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The Effects of High Density Septic Systems on Surface Water Quality in Gwinnett County, Georgia

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THE EFFECTS OF HIGH DENSITY SEPTIC SYSTEMS ON SURFACE WATER QUALITY IN GWINNETT COUNTY, GEORGIA

by

JOHN R. ANDERSON, II

Under the Direction of Lawrence Kiage

ABSTRACT

Gwinnett County, Georgia experienced rapid growth in the 1970's without the infrastructure so septic systems were installed for residential homes. The number of septic systems grew to over 85,000 with a density of 487 septic systems per square mile. This study mapped the distribution of septic systems to determine regions of potential pathogen surface water. This study addressed what potential health risks do high density septic systems have on surface water quality and how can the history of Gwinnett County assist in future development in the Metropolitan Atlanta area?

It was found that the density of septic systems has reduced the surface water quality for streams in the Yellow and Alcovy River basins. An average rainfall cause septic flushing and an increase in the fecal coliform. Other trends observed in the surface water quality of increased BOD, water temperature, and various metals also indicated this flushing effect.

INDEX WORDS: Septic systems, Fecal coliform, Gwinnett County, Drainage basin

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by

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THE EFFECTS OF HIGH DENSITY SEPTIC SYSTEMS ON SURFACE WATER QUALITY

IN GWINNETT COUNTY, GEORGIA

by

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DEDICATION

This manuscript is dedicated to my wife, Susan, who allowed me to go back to school for ANOTHER degree for my mid-life fling. She put up with me through two degrees and can say she still loves me. I also dedicate this paper to the students I have had for the past 23 years, who taught me that education can be fun even though challenging. I thank the Geosciences Department at Georgia State who allowed me to pursue this degree. Thank you for allowing me to learn from you.

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1 INTRODUCTION

1.1 Septic Systems and their Pollution Problems

One of the major sources of surface water and groundwater pollution in urban areas is septic systems (Craun, 1979, 1984, Fetter, 1994, Katz et al., 2009). A septic system is an on-site waste water treatment system for an individual home (Kaplan, 1987). Atlanta is an example of a large city where some of the city's neighborhoods, such as Gwinnett County, are still on separate septic systems. The septic system is composed of a septic tank (usually 500 to 1500 gallon tank) and the leach field or drain field, also known as the absorption field, where the liquid component of the waste water is distributed for natural purification (Kaplan, 1987, Gwinnett County Board of Health, 2006).

Both the septic tank and leach field are buried underground and disperse the wastewater into the soil. The septic tank receives the sewage and retains the solids and the liquids are dispersed to the drain field. Most septic tanks have sets of baffles that help insure proper flow within the tank and to prevent the solids from entering the drain field. The drain field is the most critical part of the septic system. It helps to reduce the contaminants and disperses the effluent, liquids (Kaplan, 1987; Gwinnett County Board of Health, 2006). Key to the function of the drain field is the soils that surround the aggregate lined trenches that contain the perforated pipes from the septic tank. The surrounding soil limits the flow of the effluent from the drain field as well as naturally filters and degrades the contaminants within the effluent. Proper maintenance of the septic tank, having it pumped every 3 to 5 years, and not allowing substances that float like fats and oils to enter the septic system which could cause the drain field to become clogged are key in maintaining a septic system (Gwinnett County Board of Health, 2006).

Septic tanks and drain fields are potential sources of groundwater pollution (Craun, 1979). It has been shown that water-borne diseases can be traced back to a point source of one or more septic systems. Infectious disease outbreaks due to septic tanks have been reported from several communities within the United States in the last thirty years (Polk County Arkansas, 1971; Yakima. Washington, 1972; A resort camp in Colorado, 1984) (Craun, 1979, 1984; Fetter, 1994). DeBorde et al. (1998) found that 42% of all water-associated disease outbreaks were associated with drinking untreated ground water impacted by septic tanks.

1.2 Groundwater pollution and pathogens

Contaminated groundwater is the most commonly reported source of waterborne disease in the United States, associated with 64% of the drinking water outbreaks between 1989 and 2002 (Fong et al., 2007). However, contamination of groundwater is not a recent phenomenon. In Ancient Rome it has been determined that shallow wells became hopelessly contaminated and had to be abandoned. Much of the contamination came from the open-hole latrines the ancient Romans used to dispose of human wastes. They recognized that these shallow water sources were not reliable for drinking water so they built aqueducts to bring clean water from the mountains to the city. This situation has occurred several times in the history of civilization (Chapelle, 1997).

One of the first documented groundwater pollution problems from human wastes in the United States is from Charleston, South Carolina. The town was built on the ridge between the Ashley and Cooper rivers. This site proved to be easily defended and a shallow supply of water supplied the town with clean drinking water. The soil in the area was able to clean the sewage effluent from the numerous shallow privies for 50 years (Chapelle, 1997). After 50 years the sewage effluent exceeded the assimilative capacity of the soil, the ability of the soil to ‘clean up’ the water, so the aquifer became polluted from the sewage. The water supply began to have a distinctive foul smell and iron oxides made the water turn a shade of red. By 1800 all the water wells in town had to be abandoned and rain-fed cisterns became the water supply for the city (Chapelle, 1997).

The inhabitants of Charleston had the impression that the groundwater aquifer could indefinitely supply water for the town and the surrounding soil could be the repository for the town’s human wastes. This perception was changed by the environmental reality that the groundwater could be contaminated to the point of being unfit for human consumption. This is becoming reality in communities all across the United States from sewage effluent (Chapelle, 1997).

Groundwater is a resource that supplies drinking water to about 100 million Americans (Craun, 1984; Meeroff, 2008; Verstraeten et al., 2004; Wicklein, 2004). With this dependence on groundwater, contaminated water has become a potential health risk. Sources of contamination come from septic tanks, urban runoff as well as agricultural, mining and industrial practices. Contamination becomes a major source of concern for those households that get their drinking water from untreated groundwater aquifers (Bitton and Gerba, 1984).

A national study showed that two-thirds of all rural households’ drinking water is chemically or bacterially unacceptable (Bitton and Gerba, 1984). Most of the problems are bacterial contamination. The use of untreated or inadequately treated groundwater has been responsible for many water-borne diseases, such as gastroenteritis, cholera, hepatitis, typhoid fever, and giardiasis. Soils function to protect or attenuate these contaminants, but some soils don't. The need to understand the factors that control the survival and transport of these pathogens through the soil is needed. The fate of pathogens in subsurface environments, microbial activity in subsurface environments, microorganisms as tracers, methodological problems in studying these microorganisms and the use of microorganisms to remediate groundwater cleanup are all areas that need to be further studied (Bitton and Gerba, 1984).

The survival and retention of bacteria and viruses in the subsurface is dependent mainly on the nature of the soil, the climate, which is measured by temperature and rainfall, and the nature of the microorganism itself. Microorganisms survive longer at low temperatures, below 4^{o} C. They can survive for months or even years at this temperature. Temperature is probability the dominant factor of virus survival. Rainfall helps to mobilize bacteria and viruses that were retained by the soil, thus the greatest degree of contamination occurs after periods of high rainfall (Gerba and Bitton, 1984).

One of the factors involved with bacteria movement through soils is filtration, the straining or sieving of the bacteria by the soil particles. Pore size plays a factor in the filtration of bacteria. The larger the pore space the less filtration will occur, thus bacteria are transported at greater rates through coarse sediments than fine sediments. Gerba and Bitton (1984) found that bacterial mats form in the soil at the drain field/soil boundary that help to trap bacteria and retain them within the soil until they degrade.

Adsorption is another factor in the removal of bacteria by soils. Adsorption occurs more in clay-rich soils where attractive forces are generated to hold onto the bacteria. The small size and platy shape of the clay particles assist with the adsorption of the bacteria. Cations in solution affect the adsorption of bacteria. Metallic cations and low pH enhance the removal of bacteria through adsorption (Gerba and Bitton, 1984).

Factors that affect the survival of enteric bacteria in soil are moisture content, temperature, pH, sunlight, organic matter, and antagonism from soil microflora. Bacteria survive longer in low temperature, high pH, and moist soils during times of high rainfall. They survive deeply buried, to a depth where very little sunlight penetrates, and has high soil organic matter (Gerba and Bitton, 1984).

Viruses survive and are transported through fine textured soils with high adsorption, low pH, and soluble organic materials. The pH of the soil is complex, generally low pH increases the adsorption of viruses, but higher pH does not necessarily mean lower adsorption of viruses. The conductivity, the measure of the ionic strength of a solution, affects the adsorption of viruses. The concentration and what cations are present affect the extent of virus adsorption of the soils. Soluble organic materials compete with viruses and bacteria for adsorption sites on the soil particles, thus organics may interfere with virus adsorption which would increase the chance of viruses migrating through the soil. Other factors involved with virus movement are the virus type, the flow rate of the groundwater and saturated versus unsaturated flow (Gerba and Bitton, 1984; DeBorde, et al., 1998).

The factors that influence the survival of viruses in soils are: temperature, desiccation, sunlight, soil pH, cations, soil texture, and biological factors. Viruses do not survive well in warm, dry, sunny soils. The soil pH affects the adsorption of the virus as well as the presences of certain cations. Soil texture affects the soil moisture which will affect the desiccation factor of the soil, thus moist soils will allow the survival of viruses. These biological factors don’t have a clear trend on how they affect the survival of viruses, but viruses are transported through soils, thus can become health risks (Gerba and Bitton, 1984).

1.3 Septic Systems and Groundwater

Domestic waste water from septic systems contain bacteria, viruses, protozoa, and helminthes which are all potential pathogens to humans. Soils complete the purification of these pathogens from the effluent of septic system drain fields (Hagedorn, 1984). They complete the process by physical filtration, chemical reaction and biological transformations of the pathogens released from the septic system (Hagedorn, 1984). The filtration process is accomplished in a properly functioning soil within two feet of the drain field – soil boundary (Hagedorn, 1984). The greatest decline of bacteria occurs in the biological mat or clogged zone that is located at the drain field and soil interface (Hagedorn, 1984). High rainfall can reduce this filtration process by saturating the soil thus allowing fecal contamination of groundwater and surface water (Hagedorn, 1984).

Studies (e.g. Hagedorn, 1984, Robertson et al., 1991, Fong et al., 2007, and Katz, 2009) have shown that bacterial transport could be disseminated through soils in high numbers over a large area in a relatively short period of time due to the flushing action of increased rainfall. Other studies (e.g. Gerba and Bitton, 1984, Nicosia et al., 2001, and Verstraeten et al., 2004) have shown that coliphages, indicators of viruses, prescription and nonprescription drugs, and organic contaminants can be transported a considerable distance from a septic system. Within a study of two septic systems in Ontario, Canada, it was found that at 130 m down gradient the bacterial concentrations were 50% those at the drain field, thus very little dilution or filtration was affecting the effluent of the septic system (Robertson et al., 1991; Wilhelm et al., 1996).

For several decades studies of subsurface behavior of septic system effluent have focused on the ability of the septic system to degrade the organic matter in the waste water and the prevention of septic system failure. Studies have dealt with the biogeochemical processes that alter domestic waste water effluent from septic systems (Wilhelm et al., 1994). It has been found that various oxidation and reduction reactions take place within a septic system. It is recognized that O_2 is the important factor in septic system functioning. If anaerobic conditions occur in the drain field severe clogging and poor waste-water treatment will occur. Below the drain field waste water typically undergoes very little aerobic oxidation because of slow diffusion rates of O_2 into the water saturated zones of the soil thus the effluent from a septic system below the drain field is untreated (Wilhelm et al., 1994).

Wilhelm et al. (1996) measured the unconfined sand aquifers beneath two operating domestic septic systems. From these samples it was determined that within the unsaturated zone that aerobic oxidation occurred to the effluent which caused the conversion of ammonium ions to nitrate, carbon to carbon dioxide, and organic sulfur to sulfate ions as predicted. As the effluent encountered the saturated zone, water table, only small amounts of oxidation occurred at each of the sites studied. Thus it was observed that little chemical degradation of septic effluent occurs in the saturated, anoxic zone of the drain field. Wilhelm et al. (1994; 1996) recommended that regulations should consider system designs that employ the addition of O_2 into the drain field that will assist in the oxidation processes of the effluent.

These studies (Wilheim et al., 1994, 1996) have shown the geochemical breakdown of bacteria occurs in the soil around the drain field, but what happens to viruses when they enter the groundwater system? Francy et al. (2004) conducted a groundwater study to determine the occurrence of viral pathogens and microbiological indicators of fecal contamination, determine whether indicators were adequate predictors of the presence of enteric viruses, and determine the factors that affect the presence of enteric viruses. Enterovirus and hepatitis A virus were found in the water wells tested. More virus-positive samples were found at sites served by septic systems than those served by sewer lines (Francy et al., 2004). Other studies by Nicosia et al. (2001) have shown that viruses are capable of being transported away from the drain field of septic systems.

These studies (Gerba and Bitton, 1984, Wilheim et al., 1994, 1996, Nicosia et al., 2001, Francy et al., 2004, and Verstraeten et al., 2004) have led to the question, what effect would several septic systems in a small area have on the groundwater? The EPA has determined that regions with greater than 40 septic systems per square mile (that is 1 system per 16 acres) are regions of potential groundwater contamination. High septic system density areas have had numerous cases of groundwater contamination reported (Yates, 1985). Groundwater contamination has been reported from Colorado, Delaware, Massachusetts, New Mexico, New York, and North Carolina all from aquifers contaminated by high density septic systems. Thus, the most important means of limiting groundwater contamination is to restrict the density of septic systems in an area (Yates, 1985).

1.4 Septic Systems and Surface Water

Given that groundwater is affected by bacteria and viruses, and the density of septic systems affects the groundwater quality, this leads to the question, if septic wastewater can travel to the groundwater will the wastewater travel to the surface and create hazardous conditions on the surface? Burns et al. (2005) looked at the effect of impervious areas, septic leach-field effluent, and wetlands on runoff generated in three small headwaters that represented a range of suburban development from high density residential to undeveloped land. Precipitation, stream discharge, and groundwater levels were monitored at 10 – 30 minute intervals for one year. Groundwater samples were collected for oxygen, nitrate, and sulfate analyses for more than two years that overlap the other data collected.

It was found that base flow for the dry period (Aug – Feb) was the greatest in the high density residential area. This was explained by septic effluent flowing through the shallow groundwater system and into the stream during this time. The moderate flow during the wet period (March – Aug.) was greatest in the undeveloped area because of a greater subsurface storage or greater hydraulic conductivity than the other sites (Burns et al., 2005).

The findings of Burns et al. (2005) show that development and impervious surface and storm drains accelerate the transport of storm runoff into streams, but the effects of natural landscape, wetlands, deep groundwater and septic systems can change the expected effects of human development on runoff and groundwater recharge.

Another study of the water quality of two tributaries of the St. Johns River near Jacksonville, Florida looked at the effect of septic leachate from residential areas adjacent to these tributaries on these tributaries (Wicklein, 2004). Samples were collected and analyzed for major ion and nutrient concentrations, fecal coliform concentrations, detection of wastewater compounds, and tracking of bacterial sources were used to document septic influences on the water quality of these tributaries (Wicklein, 2004). Water quality for these two tributaries for total nitrogen and total phosphorus concentrations exceeded the EPA nutrient criteria for rivers and streams. Organic waste water compounds detected were categorized as detergents, antioxidants, and flame retardants. Fecal coliform concentrations were measured on a monthly basis. Of the 115 samples taken 63% exceeded the State of Florida fecal coliform bacteria standards for Class III surface waters. The majority of the fecal coliform bacteria were from human sources, which most likely was from the septic systems (Wicklein, 2004).

A significant proportion of the world's population relies wholly on on-site waste treatment systems, septic systems (Dawes and Goonetilleke, 2003). The purpose of a septic system, on-site wastewater treatment system, is to assimilate the effluent into the environment. It is recognized that these systems fail and inadequate treated effluent can have serious environmental effects. The capacity of soils to treat septic waste waters changes over time. The soils ability to clean up the water diminishes over time so the septic effluent travels farther away from the source over time. The physical properties of a soil influence the rate of flow of waste water through the ground and the chemical properties of the soil dictate the ability of the soil to clean up the effluent (Dawes and Goonetilleke, 2003). Since these systems pose public health and environmental risks, strategies need to be adopted to control these risks. Thus, health risk areas need to be defined for areas of high density septic systems from scientific and historical data for these areas.

1.5 Research Question

With the expansion of Metro-Atlanta, suburbs were considered rural in the 1970's and the infrastructure for sewage was not in place so homes were built with individual septic systems. Gwinnett County had this zoning perspective as it expanded in the 1970's. Thus now there are over 100,000 homes with septic systems in the county (Gwinnett County Board of Health, 2006; Jiang and Worthington, 2005; Leo et. al., 2006). Newer subdivisions, those built since about 1993, are attached to a sewer system because sewage treatment plants have been constructed within the county.

Since water-borne pathogens can migrate from septic system effluent into groundwater systems and surface water in areas with high septic system concentrations (Yates, 1985) there is a potential health risk from these pathogens. By mapping the distribution of septic systems in Gwinnett County, Georgia, regions of high septic system use can be determined. Regions of high potential for pathogen migration to the surface can be determined by comparing the water table surface to the topography in a GIS to determine high risk zones. With pathogens migrating to the surface these high risk zones could be point sources for pathogen exposure. If these high risk zones are areas where children play there would be the need to warn the residents in these areas of potential pathogen exposure to their children. Also, the U.S.G.S. has water quality monitoring stations on the various streams within Gwinnett County. Data from these monitoring stations could be compared to the high-density septic areas to see if there is a relationship between septic systems and the surface water quality.

Therefore, this study is aimed at mapping the distribution of septic systems in Gwinnett County, Georgia, so as to determine regions of high potential for pathogen migration to the surface. A key component of the study was to use GIS to determine the high risk zones of pathogen migration to the surface that could be point sources for pathogen exposure in the county. Specifically, this study addressed the following questions:

- What pathogenic effect and potential health risks do high density septic systems have on surface water?
- How can the sewage treatment history of Gwinnett County, Georgia assist in proposing sewage infrastructure for counties in the Metropolitan Atlanta area that are experiencing development?

2. GEOGRAPHIC SETTING FOR THIS STUDY

Gwinnett County, Georgia is located in the north central portion of Georgia in the Piedmont physiographic province of the United States. The county is also in the northeastern portion of the Metropolitan Atlanta Area (Figure 1). The metropolitan Atlanta Area is made of up of 26 counties that extends from the Alabama border in the west to north-central portion of the state of Georgia.

Gwinnett County, named after Button Gwinnett one of the signatories of the Declaration of Independence, is the 50th largest county in the state of 159 counties. The total area for the county is 436.7 square miles with an estimated population in 2009 of 808,167 persons, which is about 8% of the total population of the state (US Census data, 2009).

The county experienced rapid population growth in the last several decades of the 20th century. The county was the fastest growing county in the U.S. for three consecutive years, 1986 through 1988, among counties with a population over 100,000 (Gwinnett County Board of Commissioners, 2010). The county has continued to grow in population since the late 1980's and this growth can be readily observed from near anniversary multi-temporal remote sensing imagery of the county. Figure 2 is a Landsat image of Gwinnett County acquired on October 5, 1988 that shows that the county has a considerable amount of vegetation within the county whereas in Figure 3 another Landsat image of the county acquired on September 29, 2009 there is much more commercial development with pavement and buildings and far less vegetated areas. Figure 4 is a glimpse of the land cover change that accompanied population growth in the county over a 21-year period.

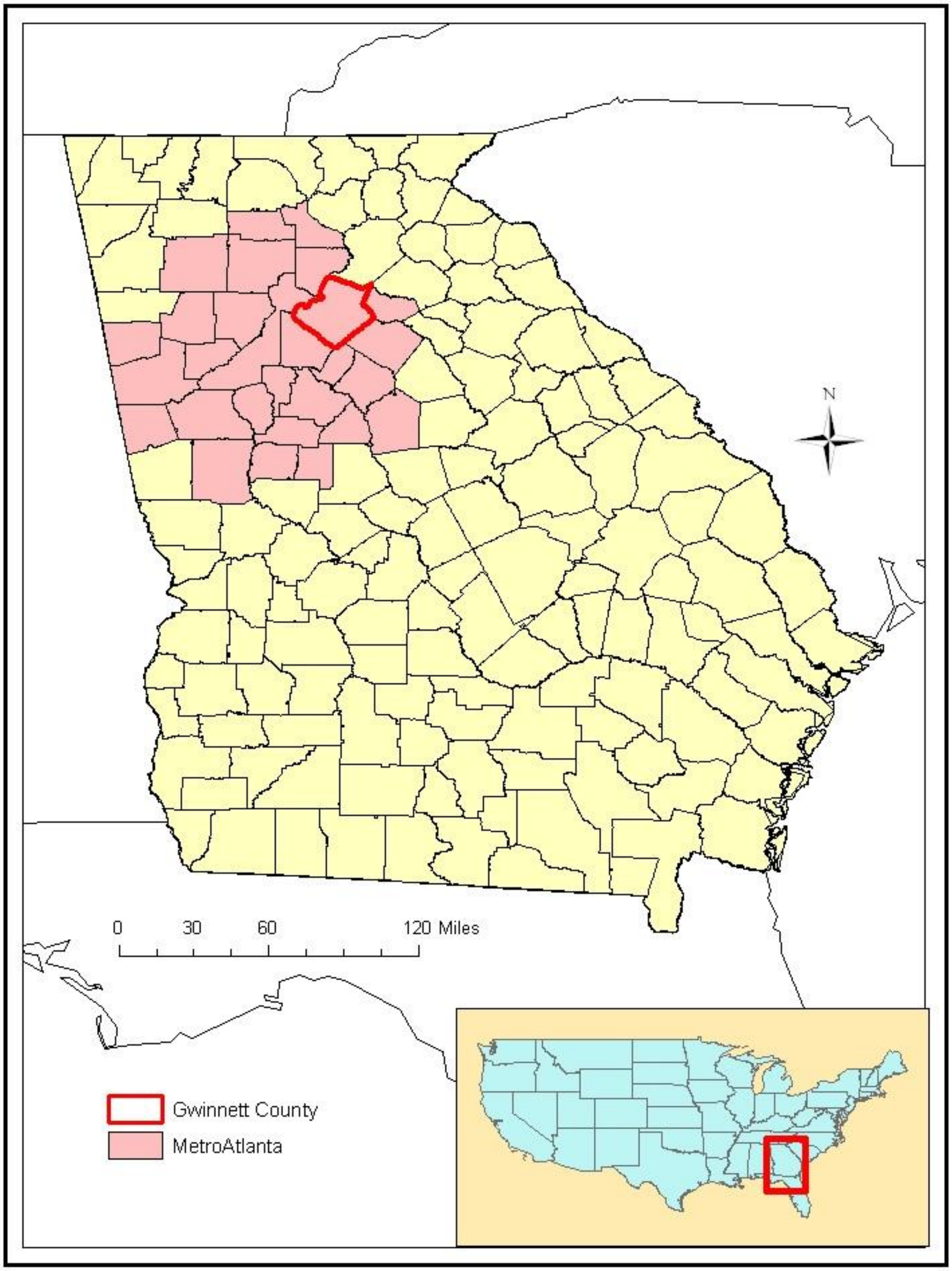

Figure 1. A map of Georgia showing the location of the Metropolitan Atlanta Area and Gwinnett County.

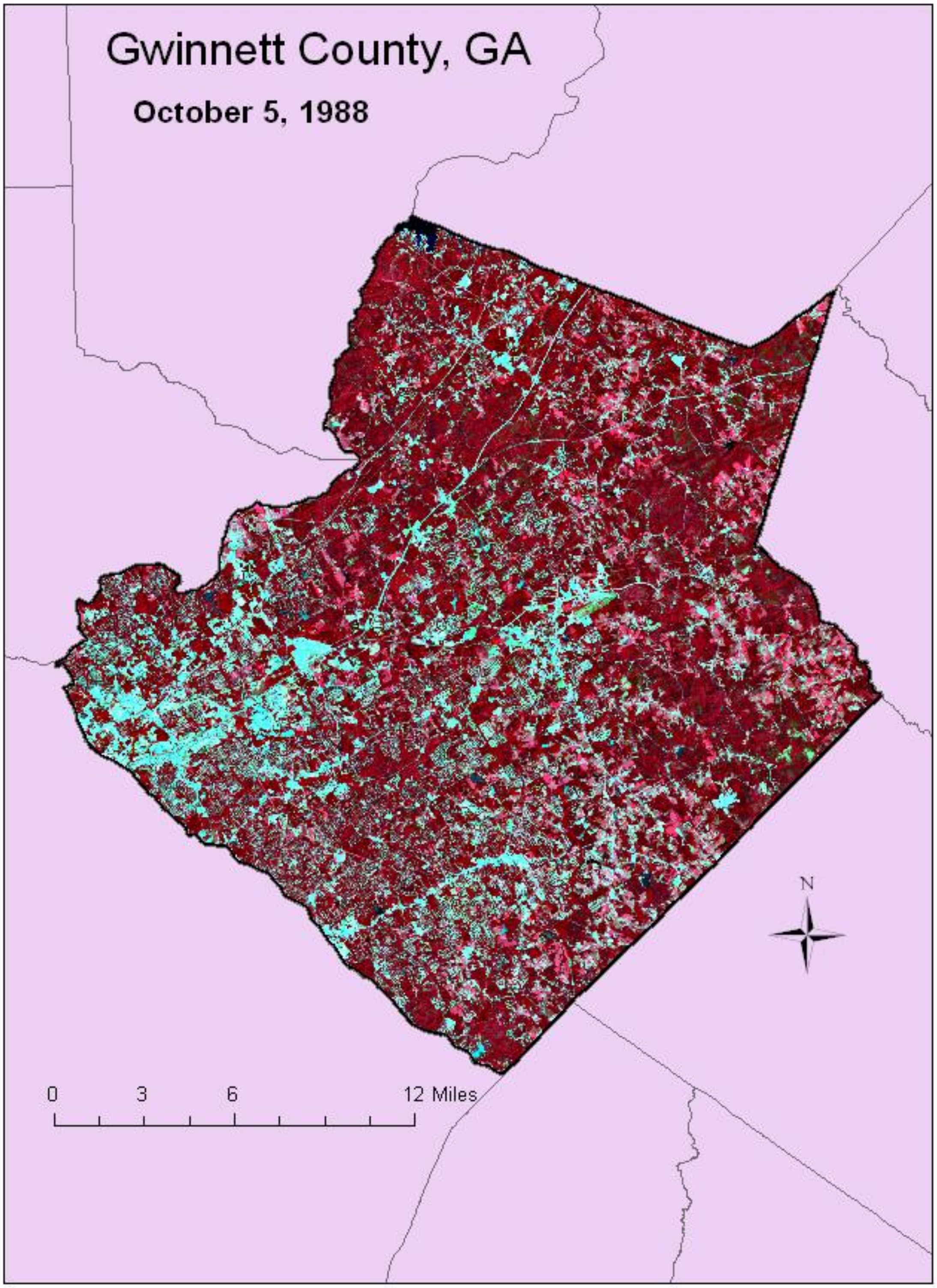

Figure 2. A map of Gwinnett County showing a false color Landsat Thematic Mapper image of the county taken on October 5, 1988 (bands 4, 3, and 2 displayed as red, green, and blue). Red in this image shows vegetation and the light blue areas are paved surfaces and buildings.

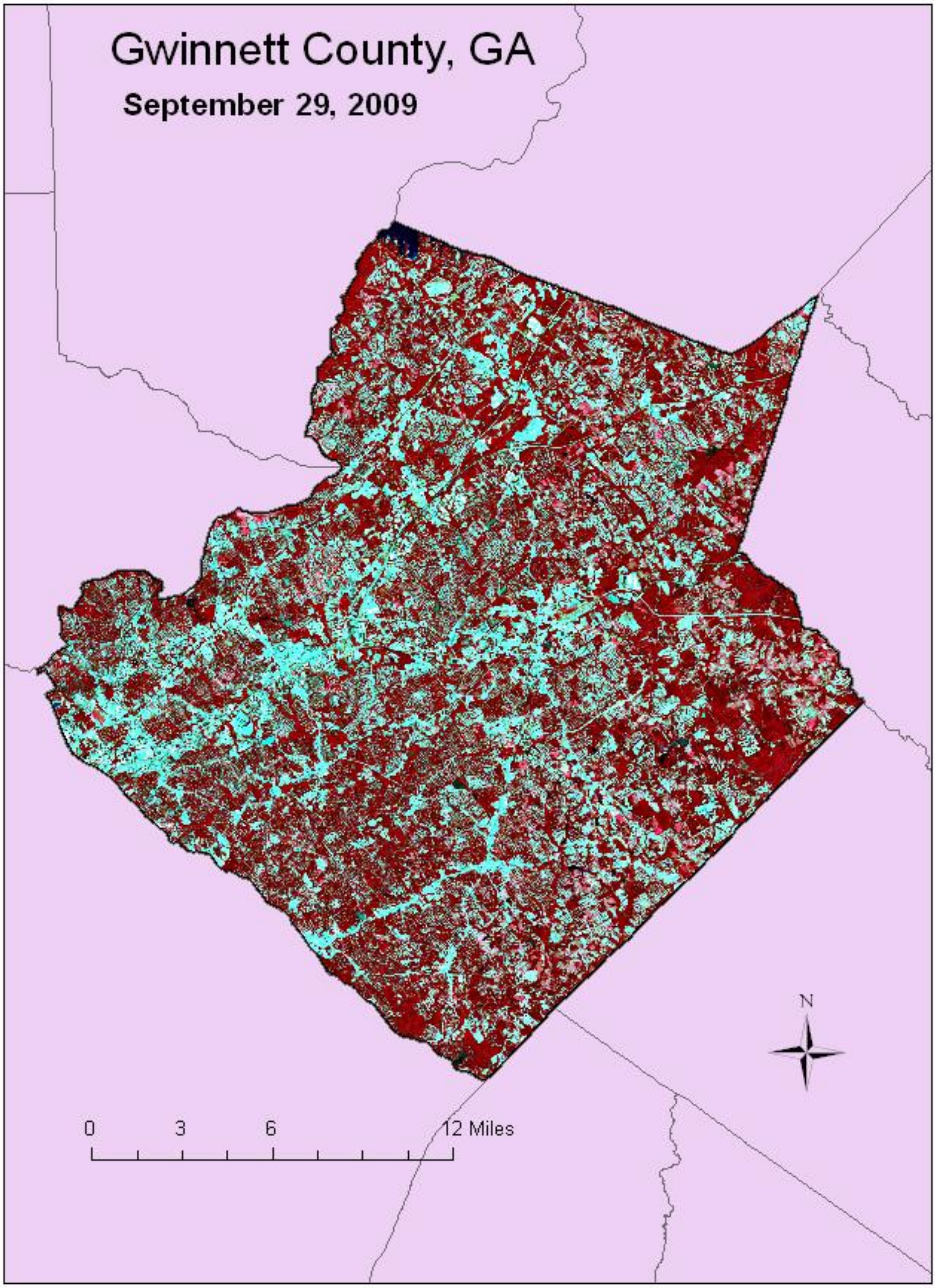

Figure 3. A map of Gwinnett County showing a false color Landsat Thematic Mapper image of the county taken on September 29, 2009 (bands 4, 3, and 2 displayed as red, green, and blue). Red in this image shows vegetation and the light blue areas are paved surfaces and buildings.

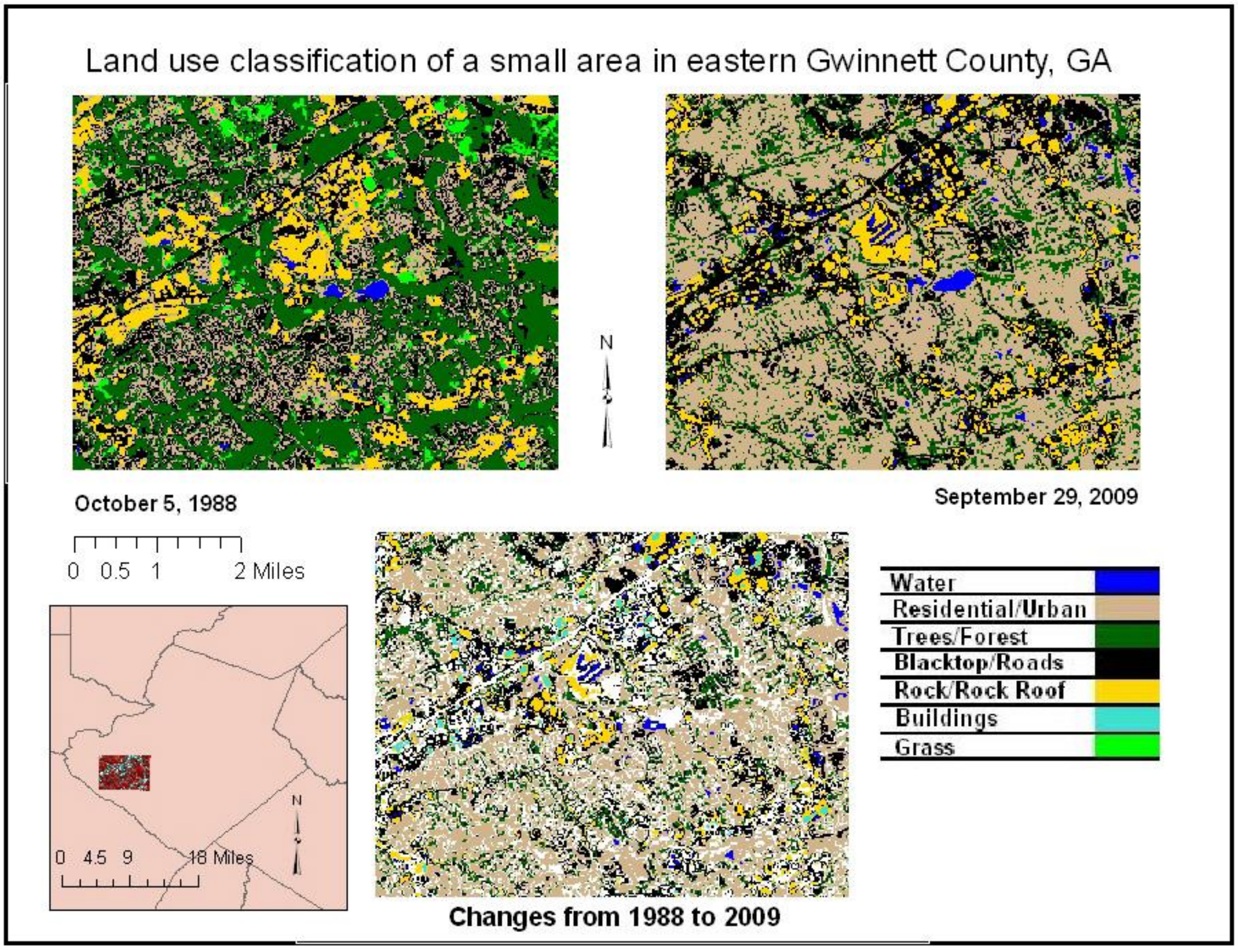

Figure 4. Land use classification of the October 5, 1988 and September 29, 2009 Landsat Thematic Mapper images for a small portion of western Gwinnett County, Georgia.

To determine the change that occurred from 1988 to 2009 each image was classified based on the unsupervised classification method that is based on the pixel values in the image. The unsupervised classification in ERDAS Imagine 9.0 created 25 classes that were then aggregated to 7 classes in the image in western Gwinnett County. Categories were based on the USGS land-use and land-cover classification system (Anderson, et al., 1976).

The initial area that was classified was the area in western Gwinnett County centered on the Vulcan Mineral Quarry along I-85 at the Beaver Ruin Road exit (See Figure 4). The 1988 and 2009 images were classified using the subdivisions of water, residential/urban, trees/forest, blacktop/roads, rock/rock roof, buildings, and grass. It was found that the bedrock being quarried has similar reflectance values to the rock roof material used on the host of commercial properties in the area so it was impossible to simply isolate the quarry from these other features. What is very noticeable between the 1988 and 2009 classifications is the decrease in trees and an increase in the amount of area that is residential. These two classifications have significant changes within the 21 year period. As can be noted in Table 1, the area that was residential in 1988 was a little over 22%, but had more than doubled by 2009. The area covered by trees on decreased over the same period, i.e. 36% and 15% in 1988 and 2009 respectively. The areas classified as blacktop/roads and rock/rock roof did not change for the most part from 1988 to 2009 which is somewhat surprising since this area has the Gwinnett Place Mall and within this time framework there has been considerable commercial development in that area. There was only 30% of this entire area (the white areas in the change map on Figure 4) that did not undergo any land-use change within the 21 year period. There was an increase in the amount of area covered by water and a decrease in the area covered by grass to no areas in 2009 being classified as grassy land-use. The greatest change for grassed areas was to blacktop/roads, which indicates that the grassy areas were converted to commercial properties.

Table 1. Land use changes for western Gwinnett County from 1988 to 2009 for the area shown in Figure 4.

Land use	1988 acreage	2009 acreage	% area 1988	% area 2009
Water	76.5	215.1	0.5	1.4
Residential/Urban	3537.2	7242.7	22.4	45.8
Trees/Forest	5704.7	2386.3	36.1	15.1
Blacktop/Roads	4325.4	4204.2	27.3	26.6
Rock/Rock roof	1711.6	1630.4	10.8	10.3
Buildings	0.0	141.7	0.0	0.9
Grass	465.0	0.0	2.94	0.0
Total	15820.3	15820.3		

3. METHODS AND DATA

3.1 Septic Systems in Gwinnett County, Georgia

A map of the properties in Gwinnett County, Georgia that are serviced by septic systems did not exist. The Division of Information Technology Services of Gwinnett County had available several shapefiles for the county, but they did not have a shapefile of the properties serviced by septic systems. The county had a shapefile of the cadastral map of all of the properties in the county. They also had a shapefile for all of the gravity sewer lines, forced sewer lines, man-holes, and pump stations. Thus from the shapefiles available it was possible to generate a map/shapefile of the properties serviced by a septic system in a GIS software (ArcMap 9.3.1).

The premise used to create this shapefile was that properties within 75 feet of a gravity sewer line would be on the sewer system for the county (Figure 5). A buffer of 75 feet was created (Figure 6) in ArcMap for all the gravity sewer lines for the county and then the properties that intersected this 75 foot buffer were selected from the cadastral map. The properties selected were those that were serviced by the county's sewer system (Figure 7). The properties on septic systems would be those not on the sewer system. Therefore, the properties with septic systems were determined by changing the selection in ArcMap to the opposite of what had been selected as sewers (Figure 8). The 75 foot buffer was determined to give a better ground truth selection of the sewer and septic system properties. Both smaller and larger buffers were tried with less accurate determination of sewer and septic properties than what was found using a 75 foot buffer. A more efficient way to determine the properties on septic systems would have been to use water bill records such that those properties that are only charged for water would be serviced by a septic system. However, those data were not available. Statistics for Gwinnett

County as to the number of commercial and residential properties, the total area in acres for the county, the acres of the county serviced by septic systems, the acres of the county serviced by the sewer system, the number of properties serviced by septic systems, and the number of properties serviced by the sewer system were created in ArcMap. From these statistics the percentage of the county serviced by septic systems and sewers was calculated for both acreage and number of properties. The number of septic systems per square mile was also calculated along with the number and area of properties that fall within the state mandated 200 feet from a sewer line which by law should be connected to the sewer system.

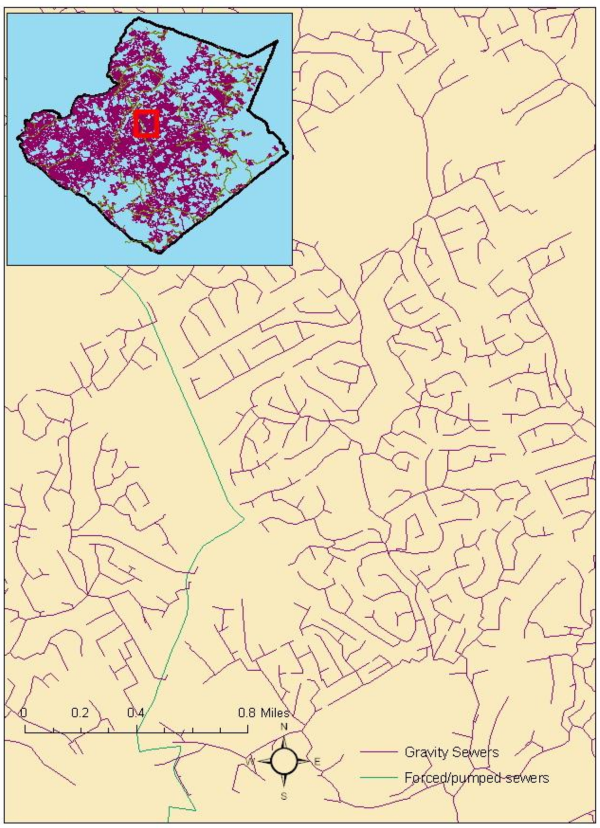

Figure 5. Close up view of a portion of Gwinnett County, Georgia showing the location of gravity and forced sewer lines.

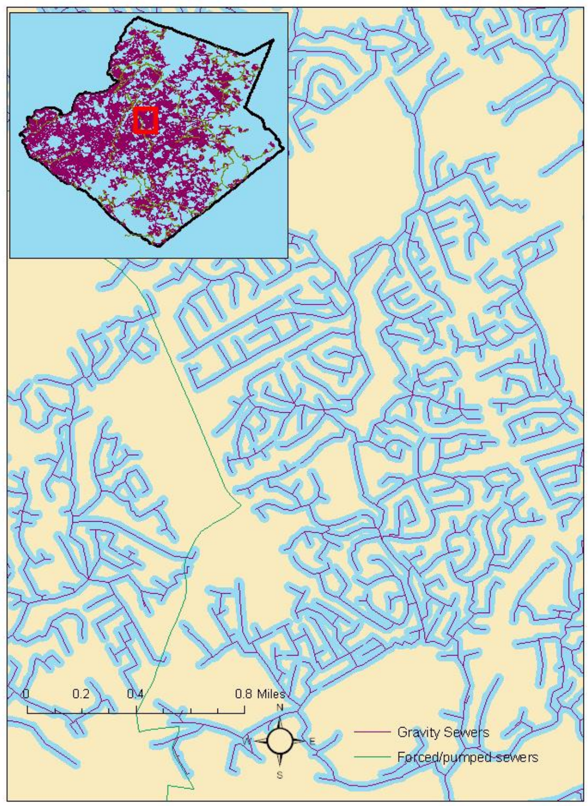

Figure 6. Close up view of a portion of Gwinnett County, Georgia showing a 75 foot buffer around the sewer lines.

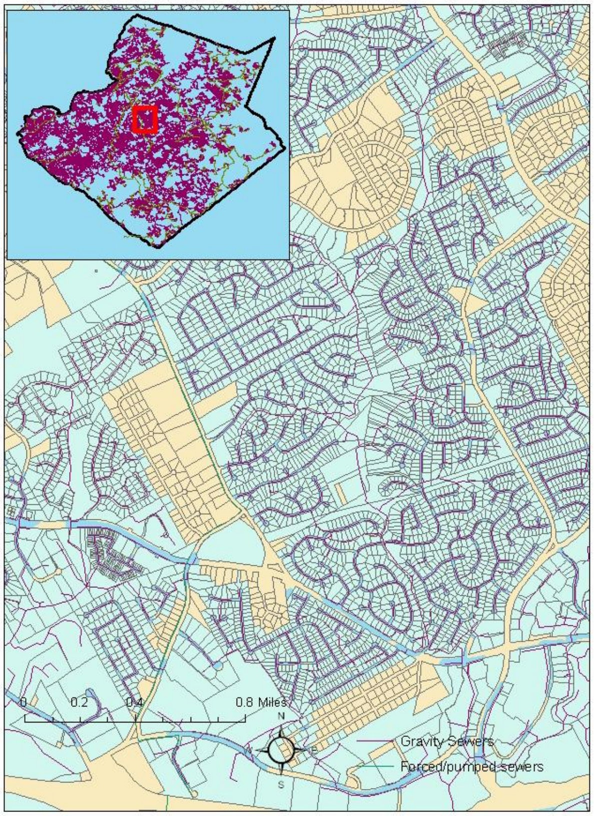

Figure 7. Close up view of a portion of Gwinnett County, Georgia showing the properties that overlap the 75 foot buffer around the sewer lines that would be the properties (in blue) serviced by the sewer system.

Figure 8. Close up view of a portion of Gwinnett County, Georgia showing the properties that were alternatively selected (in pink) that are not serviced by the sewer system which would be those properties that should be serviced by a septic system.

3.2 Water Quality Data for Gwinnett County

The water quality data for this study were acquired from the National Water Information System of the United States Geological Survey found online (http://waterdata.usgs.gov/ga/nwis/inventory) For Gwinnett County, Georgia there was a total of 364 collection sites of water data of from groundwater monitoring wells, gage stations, or water quality collections sites. Of these water data sites 208 localities were gage stations on various streams in the county. A total of 46 of those stream gage stations water quality data were collected. The time span for the data for the water quality gage stations ranged from January 1, 1901 to the near recent dates (at the time of that the data was downloaded the most recent data was May of 2010 and the data was downloaded in June of 2010). Not all of the water quality localities had data for the entire time span. The range for water quality data were from one day to 106 years.

From this extensive amount of water quality data, with a wide time range, eight water quality localities were selected for this study. Those localities were from the Yellow River basin, four locations, and the Alcovy River basin, four locations. The Yellow River basin was selected because it is the largest stream basin in the county as well as there are water reclamation facilities (WRF) (also known as waste water treatment plants) within this river basin. The Alcovy River basin localities were selected because it is the second largest river basin within the county, and there are no WRF within this basin. Thus the water quality data from this basin is the control for the comparisons of the water quality data. The four localities in each of these river basins were selected based on their location in the basin i.e. near the headwaters, midway in the basin and close to where the river exits the county. For the Yellow River basin two of the localities were upstream from the WRF and two were downstream of the WRF. The lower two localities for both river basins were along the same tributary so the water from the upstream locality flows to the lower, downstream locality. The upper two localities for both river basins were not on the same tributary so they represent separate sub-drainage basins for their respective basins. Those eight localities were also selected because their water quality data was from similar times so comparisons could be made between the various localities as well as between the two drainage basins. Figure 9 shows the location of all the water quality stations in the

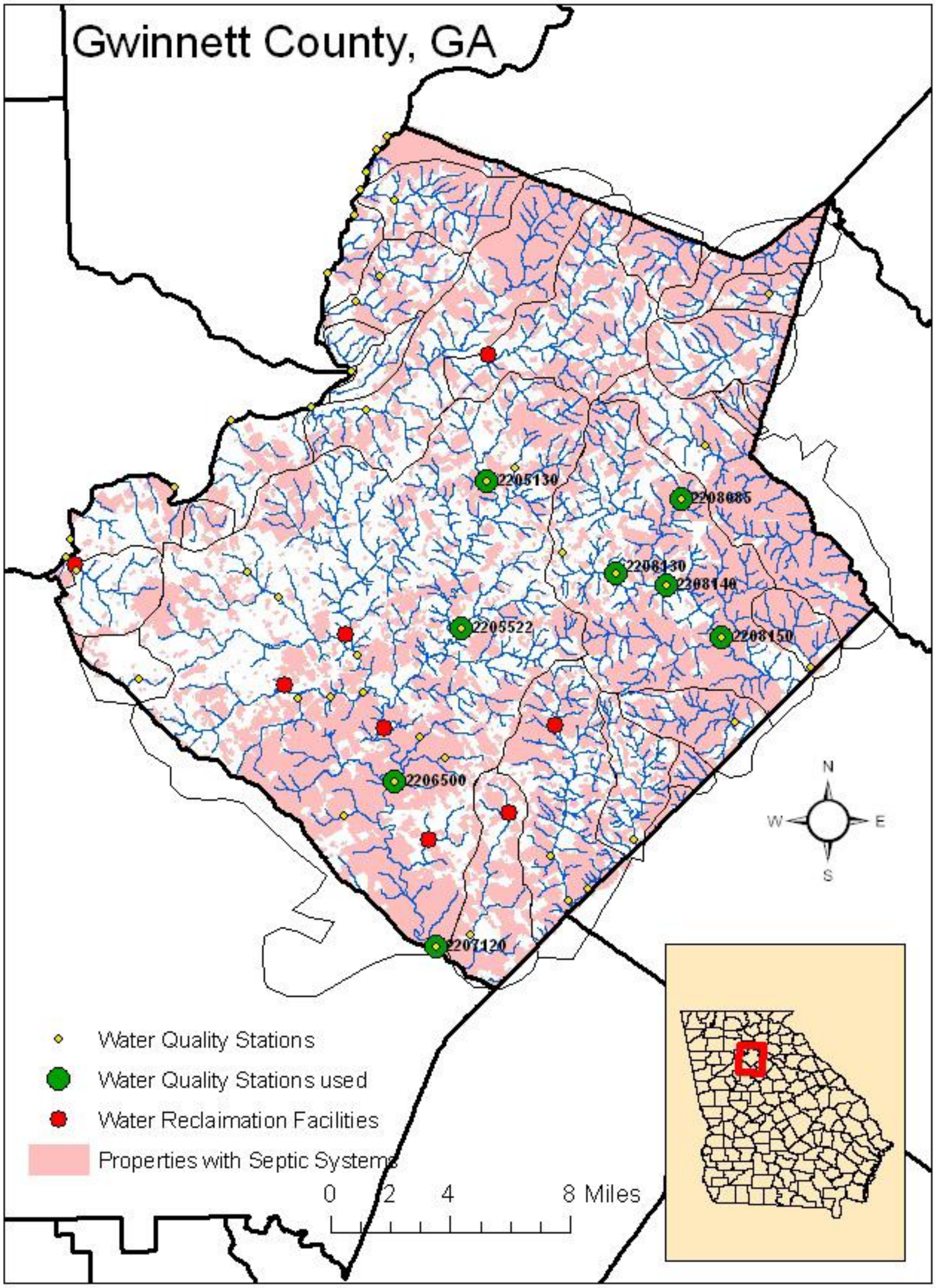

Figure 9. A map of Gwinnett County showing all of the water quality stations, the water reclamation facilities, and the water quality stations used in this study.

Table 2. U.S.G.S. Water Quality data collecting localities for this study.

Station Number	U.S.G.S. Site number	Site Name	Location	Drainage Basin	Drainage basins size (square miles)	Data collection dates	Number of data dates
Y1	2205130	Little Suwannee Creek near Lawrenceville, GA	33°59'45", 84°01'15" NAD27	Yellow River	9.62	3/8/1999 to 11/18/1999	16
Y2	2205522	Pew Creek at Patterson Rd, near Lawrenceville, GA	33°55'33", 84°02'16" NAD27	Yellow River	7.0	3/9/1999 to 5/25/2010	90
Y3	2206500	Yellow River near Snellville, GA	33°51'11", 84°04'45" NAD27	Yellow River	134	11/11/1969 to 10/7/1999	153
Y4	2207120	Yellow River at GA 124, near Lithonia, GA	33°46'22", 84°03'30" NAD27	Yellow River	162	3/14/1996 to 12/12/2007	35
A1	2208085	Hopkins Creek at Stanley Rd, near Dacula, GA	33°59'05", 83°54'34" NAD27	Alcovy River		3/9/1999 to 11/1//1999	16
A2	2208130	Shoal Creek at Paper Mill Rd, near Lawrenceville, GA	33°56'59",83°56'54" NAD83	Alcovy River	3.9	12/15/2005 to 5/25/2010	70
A3	2208140	Shoal Creek near Lawrenceville, GA	33°56'37", 83°55'10" NAD27	Alcovy River	5.24	3/9/1999 to 11/18/1999	16
A4	2208150	Alcovy River at New Hope Road, near Grayson, GA	33°55'03", 83°53'17" NAD27	Alcovy River	30.8	10/15/1996 to 12/27/2000	31

county as well as the locations of the WRF's and the locations of the eight water quality localities used within this study. Table 2 has the specifics for the eight U.S.G.S. water quality data collecting localities used within this study. Several water quality parameters were measured at these eight localities. Table 3 lists the various water quality parameters recorded at these localities that were used within this study.

Table 3. Water Quality parameters analyzed for the eight localities used within this study.

Parameter	**Localities**
Water Temperature, in ^{o}C	Y1, Y2, Y3, Y4, A1, A2, A3, A4
Air Temperature, in ^{o}C	Y1, Y2, Y3, Y4, A1, A3, A4
Barometric Pressure, in mm Hg	Y1, Y2, Y3, Y4, A1, A2, A3, A4
Discharge, in ft^3/sec	Y2, A2, A4
Instantaneous discharge, in ft^3/sec	Y2, Y3, Y4, A2, A4
Gage height, in ft.	Y2, Y3, Y4, A1, A2, A3, A4
Turbidity, water, unfiltered, nephelometric turbidity units (NTU)	Y3, Y4, A4
Specific conductance, water, unfiltered, microsiemens per centimeter at 25^{o} C	Y1, Y2, Y4, A2, A3, A4
Color of water, filtered, platinum cobalt units	Y3
Water Hydrogen ion, unfiltered, calculated, mg/liter	Y1, Y2, Y3, Y4, A1, A2, A3, A4
Dissolved oxygen, water, unfiltered, mg/liter	Y1, Y2, Y3, Y4, A1, A2, A3, A4
Dissolved oxygen, water, unfiltered, percent of saturation	Y1, Y2, Y4, A1, A2, A3, A4
Biochemical oxygen demand, water, unfiltered, 5 days at 20^{o} C, mg/ liter	Y3, Y4, A4
Chemical oxygen demand, high level, water, unfiltered, mg/liter	Y4, A4
pH, water, unfiltered, field, standard units	Y1, Y2, Y3, Y4, A1, A2, A3, A4
Suspended solids, water, unfiltered, mg/liter	Y4, A4
Total nitrogen, water, unfiltered, mg/liter	Y4, A4
Nitrate plus nitrite, water, unfiltered, mg/liter as nitrogen	Y3
Ammonia plus organic nitrogen, water, unfiltered, mg/liter as nitrogen	Y3
Organic carbon, water, unfiltered, mg/liter	Y3
Acid neutralizing capacity, water, unfiltered, fixed endpoint (pH 4.5) titration, field, milligrams per liter as calcium carbonate	Y3
Acid neutralizing capacity, water, unfiltered, fixed endpoint (pH 4.5) titration, laboratory, milligrams per liter as calcium carbonate	Y3
Carbon dioxide, water, unfiltered, mg/liter	Y3

Table 3. (continued)

Parameter	**Localities**
Ammonia plus organic nitrogen, water, unfiltered, mg/liter as nitrogen	Y4, A4
Nitrate plus nitrite, water, unfiltered, mg/liter as nitrogen	Y4, A4
Phosphorus, water, filtered, milligrams per liter as phosphorus	Y4, A4
Phosphorus, water, unfiltered, milligrams per liter as phosphorus	Y3, Y4, A4
Calcium, water, unfiltered, recoverable, mg/liter	Y4, A4
Magnesium, water, unfiltered, recoverable, mg/liter	Y4, A4
Cadmium, water, unfiltered, micrograms per liter	Y4, A4
Chromium, water, unfiltered, recoverable, micrograms per liter	Y4, A4
Copper, water, unfiltered, recoverable, micrograms per liter	Y4, A4
Iron, water, unfiltered, recoverable, micrograms per liter	Y4, A4
Lead, water, unfiltered, recoverable, micrograms per liter	Y4, A4
Manganese, water, unfiltered, recoverable, micrograms per liter	Y4, A4
Zinc, water, unfiltered, recoverable, micrograms per liter	Y4, A4
Gage height, above datum, meters	Y2, Y4, A1, A2, A3, A4
Discharge, m^3/second	Y2, A2, A4
Discharge, instantaneous, m^3/second	Y2, Y3, Y4, A2, A4
Total coliform, LES Endo method, immediate, water, colonies per 100 milliliters	Y4, A4
Total coliform, Defined Substrate Technology, water, most probable number per 100 milliliters	Y2, A2
Total coliform, LES Endo method, immediate, water, colonies per 100 milliliters	A4
Fecal coliform, M-FC MF (0.7 micron) method, water, colonies per 100 milliliters	Y2, Y4, A2, A4
Fecal coliform, EC broth method, water, most probable number per 100 milliliters	Y1, Y3, A1, A3
Escherichia coli, Defined Substrate Technology, water, most probable number per 100 milliliters	Y2, A4
Dissolved solids dried at 180 degrees Celsius, water, filtered, milligrams per liter	Y4, A4
Total nitrogen, water, unfiltered, milligrams per liter as nitrate	Y4, A4
Specific conductance, water, unfiltered, laboratory, microsiemens per centimeter at 25^{o}C	Y4, A4

3.3 Rainfall Data for Gwinnett County

Rainfall data were collected for Norcross, GA, the only weather station that had data for the time framework of the water quality data. There were gaps in the rainfall data from the Norcross weather station which were filled by rainfall data from the Alpharetta, GA station due to its close proximity. The various measures of rainfall determined for each date that water quality data was recorded were the amount of rain on the date that the water quality data (WQD) was taken, the amount of total rainfall for 7-days, 14-days, 21-days, and 28-days prior to the WQD readings, and the number of days of rainfall 7-days, 14-days, 21-days, and 28-days prior to the WQD. From these rainfall values the amount of rain per week was calculated for the 7, 14, 21, and 28 day time intervals (week prior, 2 weeks prior, 3 weeks prior, and 4 weeks prior) of WQD readings. The average total rainfall and the weekly average rainfall were also calculated for the 7, 14, 21 and 28 day intervals. Table 4 shows the various rainfall measures recorded for each water quality date as well as the various ratios calculated for the rainfall.

Table 4. Rainfall values determined for each Water Quality data point and the ratios determined.

Parameter	How it was determined
Rainfall on the date of WQD (mm)	Rainfall value on that date
Total rainfall for 7-days prior to WQD (mm)	Sum of rainfall values for 7 days prior to WQD
Total rainfall for 14-days prior to WQD (mm)	Sum of rainfall values for 14 days prior to WQD
Total rainfall for 21-days prior to WQD (mm)	Sum of rainfall values for 21 days prior to WQD
Total rainfall for 28-days prior to WQD (mm)	Sum of rainfall values for 28 days prior to WQD
Number of days of rain 7-day interval	Count the number of days of rain in 7-day interval
Number of days of rain 14-day interval	Count the number of days of rain in 14-day interval
Number of days of rain 21-day interval	Count the number of days of rain in 21-day interval
Number of days of rain 28-day interval	Count the number of days of rain in 28-day interval
Amount of rain 1 week prior (mm)	Sum of rainfall for 1 week prior to WQD
Amount of rain 2 week prior (mm)	Sum of rainfall for 2 week prior to WQD
Amount of rain 3 week prior (mm)	Sum of rainfall for 3 week prior to WQD
Amount of rain 4 week prior (mm)	Sum of rainfall for 4 week prior to WQD

Table 4 (continued)

Parameter	How it was determined
Number of days of rain for week 1 prior	Count the number of days of rain for week 1 prior
Number of days of rain for week 2 prior	Count the number of days of rain for week 2 prior
Number of days of rain for week 3 prior	Count the number of days of rain for week 3 prior
Number of days of rain for week 4 prior	Count the number of days of rain for week 4 prior
Average rainfall for 7-day interval (mm/day)	Total rainfall for 7-day/number of rain days 7-day
Average rainfall for 14-day interval (mm/day)	Total rainfall for 14-day/number of rain days 14-day
Average rainfall for 21-day interval (mm/day)	Total rainfall for 21-day/number of rain days 21-day
Average rainfall for 28-day interval (mm/day)	Total rainfall for 28-day/number of rain days 28-day
Average rainfall for week 1 (mm/day)	Rainfall total for week 1/number of rain days week 1
Average rainfall for week 2 (mm/day)	Rainfall total for week 2/number of rain days week 2
Average rainfall for week 3 (mm/day)	Rainfall total for week 3/number of rain days week 3
Average rainfall for week 4 (mm/day)	Rainfall total for week 4/number of rain days week 4
Amount of rainfall 1 rain event prior to WQD	Sum of the amount of rainfall in one rain event prior
Number of days prior to rain event	Count the number of days prior to WQD that it rained
Number of days of rain for first rain event	Count the number of days of rain in the rain event
Average rain per day for first rain event (mm/day)	Amount of rainfall in rain event/number of days of rain in event

3.4 Data Analysis

Standard statistical measures (mean, media, mode, standard deviation, skewness and kurtosis) were determined for each of the water quality parameters for each of the eight localities. Both Pearson Product-Moment correlation and Spearman's Rho correlation coefficients were determined between each of the water quality parameters. Those parameters with a significant correlation with fecal coliform, total coliform or E. coli at the significance level of 0.1 were looked at for linear relationship. Those correlations with one tailed significance level of $\leq$ 0.05 were monitored more closely than those between 0.05 to 0.1 significance levels. Scatter plot graphs of the data were generated to show the linear relationships of the data. A linear regression model was determined for those two parameters that showed a significant Pearson Product-Moment correlation for those data sets that were parametric as well as those that showed a significant Spearman's Rho correlation for the non-parametric data sets.

For the year 1999 there was water quality data for seven of the eight localities used in this study, annual trends were looked at for this year. Graphs of rainfall per day were generated that were combined with the amount of fecal coliform on the dates of the water quality data collection. Graphs of water temperature combined with the amount of fecal coliform for the dates of the water quality data collected were generated as well. These graphs were generated for the entire year for 1999 as well as individual months of the year to observe the trends within the data.

4. RESULTS

The residential and commercial properties serviced by septic systems were created in ArcMap (9.3.1) using the procedures discussed within the methods sections. Figure 10 shows the properties with septic systems and the properties on the sewer system. From this map it was possible to determine the amount of area in acres and square miles that each of these properties covered within the county. Table 5 has the various measures for the county as to the area with septic systems and the area serviced by the sewer system, the percentage of the county with septic and with sewer, along with the measures of area of the county that should be on the sewer system based on state law as to properties within 200 feet of a sewer line. Figure 11 shows the areas of the county with septic systems and areas serviced by the sewer system in relationship of the major towns within the county as well as the major roads and highways. Figure 12 shows the septic and sewer areas within the county with the area that should be on the sewer system based on the properties proximity to a sewer line as mandated by Georgia law.

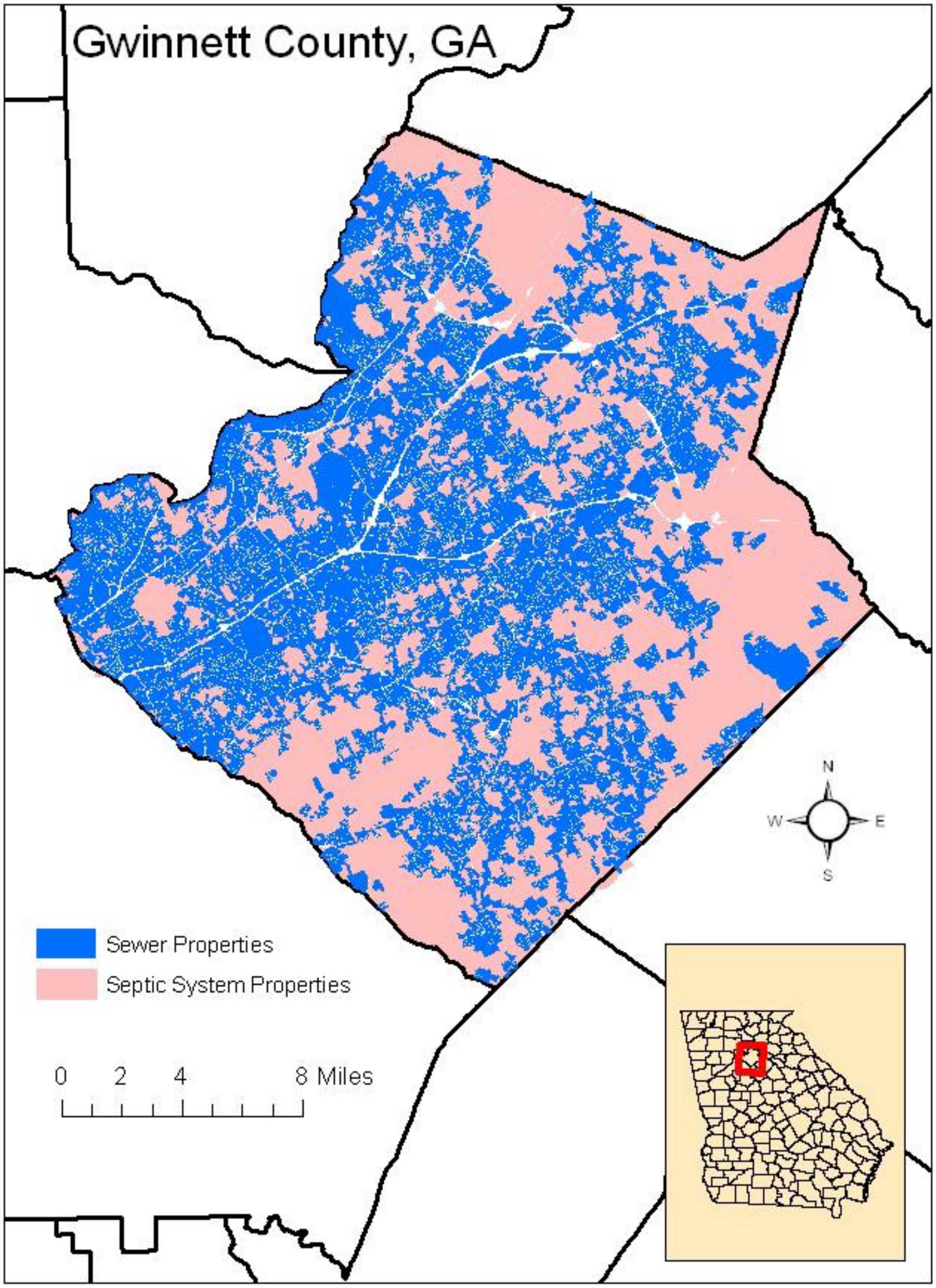

Figure 10. Properties in Gwinnett County, Georgia that were on sewers and those that have septic systems.

Table 5. Gwinnet County area data from Septic-Sewer properties map.

	Acres	Square miles	Number of properties	Percent of county – acres	Percent of county – number of properties
Entire county	247888.14	387.33	263856		
Septic area	112392.22	175.61	85574	45%	32%
Sewer area	135495.92	211.71	178282	55%	68%
Should be septic – 200 ft	54870.62	85.74	29395		
If 200 ft. enforced					
Sewer area	190366.54	297.45	207677	77%	79%
Septic area	57521.60	89.88	56179	23%	21%
	Mean property acreage	Maximum property acreage			Septic systems/mile^2
Entire count	0.94	1124.09			
Septic area	1.31	1124.09		Septic area now	487
Sewer area	0.76	940.18		Septic area if	625

The summary statistics of mean, median, mode, standard deviation, skewness and kurtosis for the Yellow River basin and Alcovy basin were calculated, Results of these calculations are shown in the Appendices. Correlation coefficients were calculated for all water quality measures, but the correlations that were looked at more closely were those correlation coefficients with fecal coliform. Fecal coliform has a relationship with water pollution coming from septic systems, thus these correlations were focused on. The water quality parameters with a significant (to the 95% confidence interval {$\alpha = 0.05$}) correlation with fecal coliform for the Yellow River and Alcovy River Basins are shown in Tables 6 and 7. Pearson's Product-Moment Correlation with fecal coliform were calculated for those samples with sample sizes greater than or equal to 30 (i.e.$N \geq 30$), where Spearman Rank (Rho) Correlation were calculated for those

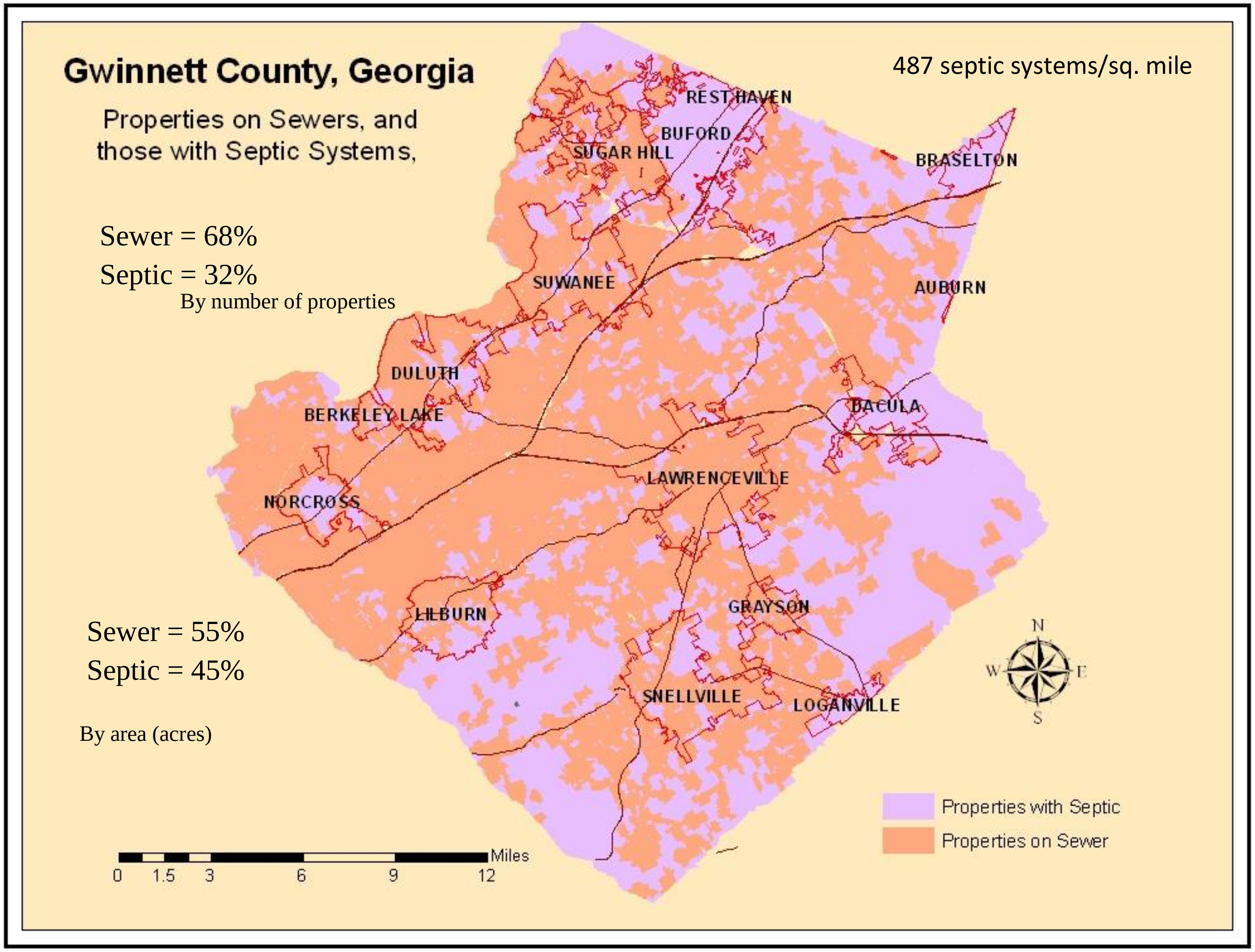

Figure 11. Map of Gwinnett County, GA showing the area with septic systems and the areas serviced by the sewer system in reference to the towns in the county.

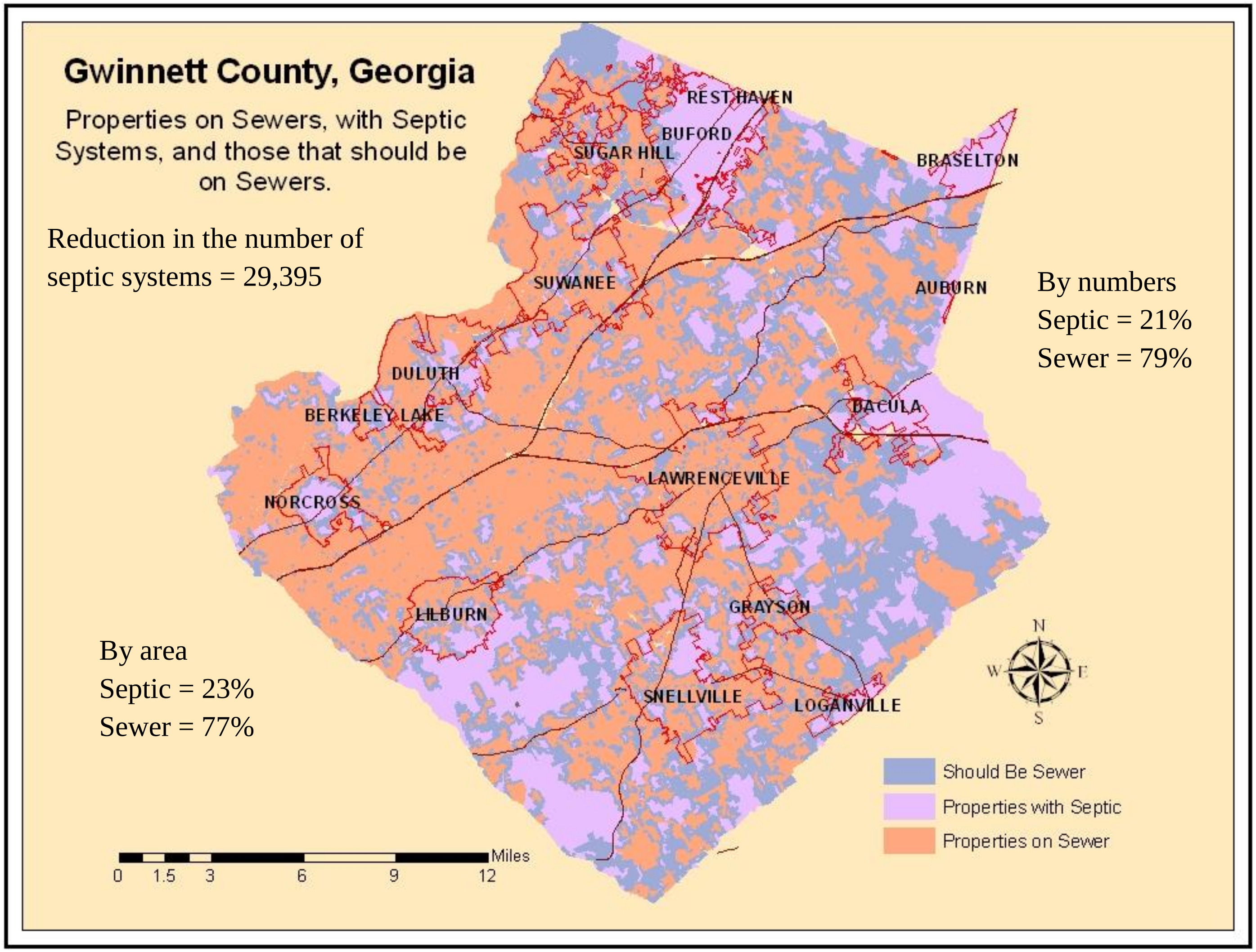

Figure 12. Map of Gwinnett County, GA showing the area of the county that should have been serviced by the sewer system based on the state law that properties within 200 feet of a sewer line should be placed on the sewer system.

Table 6. Pearson's Product-Moment Correlations and Spearman Rank (Rho) Correlations for those parameters with a significant, to the 95% confidence interval (α = 0.05 significant level), correlation with fecal coliform from the Yellow River Basin of Gwinnett County, GA.

	Station Y1	2205130	
Parameter	Pearson	Significance	N
Rain28	**.544**	0.015	16
WatTemp	**.431**	0.048	16
Parameter	Spearman	Significance	N
TotRain14	-.450	0.040	16
TotRain21	-.442	0.043	16
DisO	-.441	0.044	16

	Station Y2	2205522	
Parameter	Pearson	Significance	N
Tcoliform	.589	<.01	58
Ecoli	.539	<.01	58
Sconduct	-.352	.001	78
DaysPrior	-.218	.020	89
DRain14	.203	.028	89
WatTemp	.198	.041	78

	Station Y3	2206500	
Parameter	Pearson	Significance	N
PtCoColor	**0.654**	<.001	38
Gage	**0.353**	<.001	132
TurbidN	**0.438**	<.001	80
Duration	**0.316**	<.001	153
BOD,	**0.309**	<.001	143
RainOnD	**0.291**	<.001	153
Fdischar	**0.271**	<.001	145
MDischar	**0.271**	<.001	145
DRain7	**0.258**	0.001	153
DRain7	**0.258**	0.001	153
DaysW1	**0.258**	0.001	153
OrgCarb	**0.253**	0.002	94
Phosphor	**0.242**	0.002	138
TotRain7	**0.221**	0.003	153
Rain7	**0.221**	0.003	153

	Station Y4	2207120	
Parameter	Pearson	Significance	N
BOD	.830	.<.001	31
Mnunfil	.980	<.001	9
Cdunfil	.637	<.001	34
Tcoliform	.634	<.001	33
FeUnfil	.864	0.001	9
Sconduclab	-.622	0.002	20
IdischargeM	.482	0.003	30
IdischF	.480	0.004	29
Rain7	.427	0.006	34
Rain7	.427	0.006	34
TotRain7	.427	0.006	34
GageH	.445	0.006	31
Gage	.445	0.006	31
RainOnD	.377	0.014	34
Calciumunfil	-.465	0.015	22

Table 6. (continued)

Parameter	Pearson	Significance	N
Bpress	-0.240	0.008	99
DRain14	0.184	0.011	153
MgAmmon	0.233	0.012	94
TurbidJ	0.273	0.015	64
Conduc	-0.182	0.015	143
Nitrite	-0.185	0.015	138
TotRain21	0.172	0.017	153
DO	-0.177	0.020	136
Wtemp	0.155	0.036	136
Rain21	0.145	0.037	153

Parameter	Pearson	Significance	N
PhosphorUn	.362	0.018	34
DisSol	-.351	0.021	34
DRain7	.350	0.021	34
DaysW1	.350	0.021	34
Turbid	.372	0.021	30
Mgunfil	.433	0.022	22
Hion	.339	0.031	31
Nitr2Un	-.312	0.036	34
SSol	.316	0.037	33
NH3OrgNitro	.310	0.037	34
Sconduct	-.325	0.037	31
FieldpH	-.324	0.038	31
Crunfil	.308	0.040	33
Cuunfil	.295	0.045	34

Table 7. Pearson's Product-Moment Correlations and Spearman Rank (Rho) Correlations for those parameters with a significant, to the 95% confidence interval (α = 0.05 significant level), correlation with fecal coliform from the Alcovy River Basin of Gwinnett County, GA.

Station A1	Spearman	Significance	N
AirTemp	**.518**	**0.020**	**16**
WatTemp	.448	0.041	16

Station A3	Pearson	Significance	N
TotRain7	.445	0.042	16
Rain7	.445	0.042	16
TotRain28	.442	0.043	16

Station A3	Spearman	Significance	N
TotRain7	.526	0.018	16
Rain7	.526	0.018	16
Gage	.469	0.033	16
GageH	.469	0.033	16

Station A4	Pearson	Significance	N
Pbunfil	.757	.<.001	28
Znunfil	.753	.<.001	28
Cuunfil	.686	.<.001	28
COD	.685	.<.001	28
Tcoliform	.668	.<.001	29
NH3OrgNitro	.650	.<.001	29
PhosphorUn	.648	.<.001	29
RainOnD	.639	.<.001	30
Crunfil	.648	.<.001	28
Mnunfil	.807	.<.001	13
SSol	.571	0.001	28
BOD	.552	0.002	26
Turbid	.471	0.007	27
Hion	.447	0.007	30
Mgunfil	.507	0.007	23
TNitroNO3	.577	0.008	17
TNitro	.570	0.008	17

Station A2	Pearson	Significance	N
Ecoli	.858	.<.001	59
IdischargeM	.555	.<.001	52
IDischF	.554	.<.001	52
TotRain14	.365	0.001	70
Rain14	.298	0.006	70
DaysW2	.264	0.014	70
TotRain21	.257	0.016	70
Ave7Rain	.248	0.024	64
DRain14	.234	0.026	70
W1AveR	.244	0.027	63
amountPday	.228	0.029	70
Ave21Rain	*.220*	*0.034*	*70*
DuratAmount	.215	0.037	70
Sconduct	-.247	0.039	52
DaysPrior	-.203	0.046	70
TotRain7	.200	0.048	70
Rain7	.200	0.048	70
Ave14Rain	.200	0.049	70

Station A4	Pearson	Significance	N
DRain7	.408	0.013	30
DaysW1	.408	0.013	30
FeUnfil	.612	0.013	13
amountPday	.394	0.016	30
FieldpH,	-.374	0.021	30
DaysW4	-.369	0.022	30
DisO	-.373	0.025	28
WatTemp	.359	0.028	29
Gage	.384	0.032	24
GageH	.384	0.032	24
Sconduct	-.306	0.050	30

sample sizes less than 30 (i.e. N < 30). The Spearman Rank (Rho) correlation allows for the measure of non-parametric correlation with fecal coliform for those parameters at the 95% confidence interval. Scatter plots for each of the water quality and rainfall parameters that were found to be significantly correlated with fecal coliform were produced. Least-squared linear regression lines were plotted for each of these scatter plots. The equation of the line was determined and the coefficients of determination (R^2) values were calculated for each line of regression. The summary of these linear regressions are shown in Table 8.

Relationships between the Yellow River basin and the Alcovy River basin were best observed between the Yellow River basin station 2 to the Alcovy River basin station 2 as well as the Yellow River basing station 4 to the Alcovy River basin station 4. Stations Y2 and A2 were compared for the years 2005 through 2010 (November 2005 to May 2010 was the time frame). Station Y4 and A4 were compared for the years 1996 to 2000 (March 1996 to December 2000 was the time frame). There were more water quality parameters measured from stations Y4 and A4 than what was measured from stations Y2 and A2.

There were a number of metals detected in the water from stations Y4 and A4. Lead, Zinc, Copper, Chromium, Manganese, Magnesium, and Iron were measured from these two localities. Figures 13 through 19 show the relationships of these metals to fecal coliform at these two localities.

Table 8. Linear Regression lines and coefficient of determination (R^2) for the water quality parameters that were found to have a significant correlation with fecal coliform for each collecting locality on the Yellow and Alcovy Rivers, Gwinnett County, Georgia.

Little Suwannee Creek near Lawrenceville, GA, 2205130, Yellow River Basin Station 1			
Correlated Property	Slope	y-intercept	Coefficient of determination (R^2)
Total Rainfall 14-days	-0.0091	60.275	0.1666
Total Rainfall 21-days	-0.0099	86.235	0.2520
Dissolved Oxygen	-0.0003	9.3181	0.1385

Pew Creek at Patterson Road, near Lawrenceville, GA, 2205522, Yellow River Basin station 2			
Correlated Property	Slope	y-intercept	Coefficient of determination (R^2)
Total Coliform	10.442	8207.3	0.3470
E. coli	0.3125	347.99	0.2907
Specific Conductance	-0.0031	104.18	0.1242
Days prior to reading that it rained	-0.0004	3.1208	0.0474
Number of days of rainfall within 14-days of reading	0.0002	4.1804	0.0413
Water Temperature	0.0007	14.105	0.0392

Yellow River near Snellville, 2206500, Yellow River Basin station 3			
Correlated Property	Slope	y-intercept	Coefficient of determination (R^2)
Color of water (Pt-Co units)	0.0021	53.41	0.4271
Gage Height (ft)	4E-05	1.8837	0.1247
Turbidity NTU	0.0022	22.735	0.1916
Duration of first rainfall event prior to reading	3E-05	1.8105	0.1001
Biochemical Oxygen Demand	2E-05	1.2401	0.0955
Amount of rainfall on the day of reading	0.0001	1.7004	0.0848
Discharge - ft^3/sec	0.0057	165.68	0.0736
Discharge – m^3/sec	0.0002	4.6924	0.0735
Number of days of rain within 7 days of reading	3E-05	1.8144	0.0666
Organic carbon	5E-05	3.6202	0.0641
Phosphorus – mg/l	2E-06	0.1044	0.0584
Total rainfall 7 days prior to reading	0.0004	22.311	0.0487
Barometric Pressure	-0.0002	744.99	0.0578
Number of days of rain within 14 days of reading	3E-05	3.8283	0.0339
Magnesium – Ammonia	8E-06	0.1289	0.0541
Turbidity - J	0.0008	32.816	0.0743
Conduction	-0.0008	119.85	0.0332
Nitrate plus nitrite	-1E-05	1.1083	0.0341
Total rainfall 21 days prior to reading	0.0008	75.3	0.0295
Dissolved Oxygen	-3E-05	8.8918	0.0312
Water Temperature	9E-05	15.203	0.0241
Amount of rainfall during week 3 prior to reading	0.0003	25.878	0.0210

Table 8. (continued)

Yellow River near Lithonia, 2207120, Yellow River Basin station 4			
Correlated Property	Slope	y-intercept	Coefficient of determination (R^2)
Biochemical Oxygen Demand	0.0003	1.3673	0.6885
Manganese, unfiltered	5E-05	2.5512	0.1871
Cadmium, unfiltered	4E-06	0.5048	0.4057
Total Coliform	1.9195	13831	0.4019
Iron, unfiltered	2.1391	1229.6	0.7468
Specific conductance – lab measurement	-0.0057	169.46	0.3872
Instantaneous discharge – m^3/sec	0.0005	13.131	0.2327
Instantaneous discharge – ft^3/sec	0.0184	479.18	0.2301
Total rainfall 7 days prior to reading	0.0007	24.564	0.1821
Gage Height in m	1E-05	1.3051	0.1976
Gage Height in ft	4E-05	4.2814	0.1976
Amount of rainfall on the day of reading	0.0004	11.933	0.1420
Calcium, unfiltered	-0.0003	11.891	0.2167
Phosphorus, unfiltered	3E-06	0.0915	0.1311
Dissolved solids	-0.0006	94.402	0.1235
Number of days of rain 7 days prior to reading	3E-05	1.6697	0.1226
Turbidity	0.0033	69.197	0.1384
Magnesium, unfiltered	5E-05	2.5512	0.1871
Hydrogen Ion concentration	3E-09	0.0002	0.1151
Nitrate plus nitrite	-1E-05	1.6285	0.0973
Suspended solids	0.0046	113.22	0.0997
Ammonia plus organic nitrogen	1E-05	0.6172	0.0962
Specific conductance	-0.0007	152.69	0.1054
pH taken in the field	-7E-06	6.9689	0.1049
Chromium, unfiltered	0.0001	3.8036	0.0950
Copper, unfiltered	0.0001	3.6323	0.0871
Hopkins Creek – 2208085 – Alcovy Station 1			
Correlated Property	Slope	y-intercept	Coefficient of determination (R^2)
Air Temperature	0.0113	15.283	0.1140
Water Temperature	0.0095	12.158	0.1481
Shoal Creek at Paper Mill Road near Lawrenceville, GA 2208130 – Alcovy Station 2			
Correlated Property	Slope	y-intercept	Coefficient of determination (R^2)
E. coli	2.2139	- 551.19	0.7365
Instantaneous discharge, m^3/sec	9E-05	0.0561	0.3076
Instantaneous discharge, ft^3/sec	0.0032	1.9821	0.3072
Total rainfall 14 days prior to reading	0.0065	39.251	0.1335
Rainfall in week 2 prior to reading	0.0033	19.031	0.0889

Table 8. (continued)

Alcovy Station 2 (continued)			
Correlated Property	Slope	y-intercept	Coefficient of determination (R^2)
Number of days of rain in week 2 prior to reading	0.0002	2.1439	0.0695
Total rainfall 21 days prior to reading	0.0062	59.718	0.0660
Average rainfall 7 days prior to reading	0.0013	8.4013	0.0613
Number of days of rainfall 14 days prior to reading	0.0002	4.3603	0.0546
Average rainfall one week prior to reading	0.0013	8.5565	0.0595
Amount of rain per day, first rain event prior to reading	0.0014	9.3364	0.0518
Average rainfall 21 days prior to reading	0.0007	8.8847	0.0484
Amount of the first rain event prior to reading	0.0032	17.058	0.0461
Specific conductance	-0.0011	81.402	0.0611
Number of days prior to first rainfall before reading	-0.0003	2.5183	0.0414
Total rainfall 7 days prior to reading	0.0032	20.221	0.0401
Average rainfall 14 days prior to reading	0.0009	9.5047	0.0398
Shoal Creek near Lawrenceville – 2208140 – Alcovy station 3			
Correlated Property	Slope	y-intercept	Coefficient of determination (R^2)
Total rainfall 7 days prior to reading	0.0169	9.3242	0.1977
Gage Height in feet	6E-05	1.9553	0.0508
Gage Height in m	2E-05	0.5959	0.0509
Alcovy River at New Hope Road near Grayson, 2208150 – Alcovy Station 4			
Correlated Property	Slope	y-intercept	Coefficient of determination (R^2)
Lead, unfiltered	0.0128	-1.2884	0.5730
Zinc, unfiltered	0.0409	- 3.532	0.5666
Copper, unfiltered	0.0095	- 2.4469	0.4703
Chemical Oxygen Demand	0.0048	7.1014	0.4697
Total Coliform	4.2813	1087.5	0.4468
Ammonia plus organic Nitrogen	0.0003	0.3384	0.4227
Phosphorus, unfiltered	5E-05	0.0446	0.4198
Rain amount on the day of the reading	0.0049	2.3392	0.4079
Chromium, unfiltered	0.0159	- 5.4206	0.4200
Manganese, unfiltered	0.2418	311.47	0.6516
Suspended Solids	0.0987	73.23	0.3265
Biochemical Oxygen Demand	0.0005	1.6097	0.3052
Turbidity	0.0356	52.268	0.2219
Hydrogen Ion concentration	9E-08	0.0004	0.1998
Magnesium, unfiltered	0.0002	1.6045	0.2574
Total Nitrogen plus nitrate	0.0013	4.2054	0.3334
Total Nitrogen	0.0003	0.949	0.3254
Number of days of rain 7 days prior to reading	0.0003	1.1905	0.1669
Iron, Unfiltered	2.8592	2758.2	0.3743

Table 8. (continued)

Alcovy Station 4 (continued)			
Correlated Property	Slope	y-intercept	Coefficient of determination (R^2)
Amount of rainfall per day prior to reading	0.0023	11.332	0.1550
ph measured in the field	-8E-05	6.5361	0.1395
Number of days of rainfall 4 weeks prior to reading	-0.0003	2.5885	0.1365
Dissolved Oxygen	-0.0004	9.7461	0.1392
Water Temperature	0.0013	14.011	0.1287
Gage Height in m	0.0003	3.3464	0.1472
Gage Height in feet	9E-05	1.0203	0.1472
Specific Conductance	-0.0047	77.613	0.0939

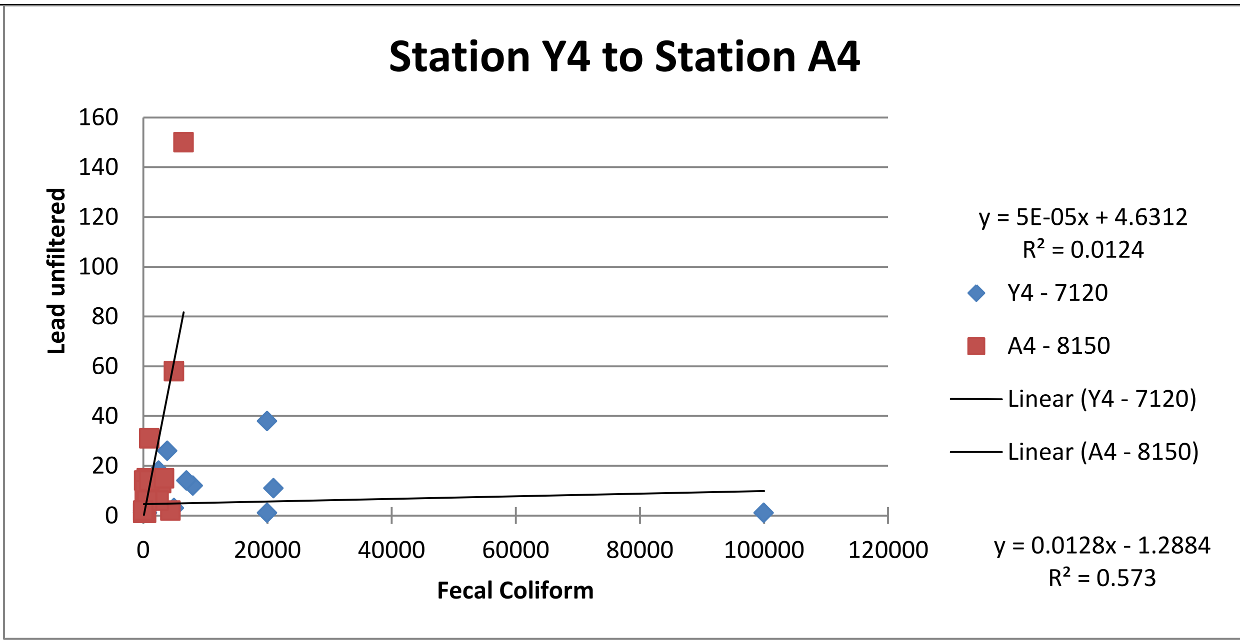

Figure 13. Relationship of Lead to fecal coliform at the Yellow River Station 4 and the Alcovy River station 4.

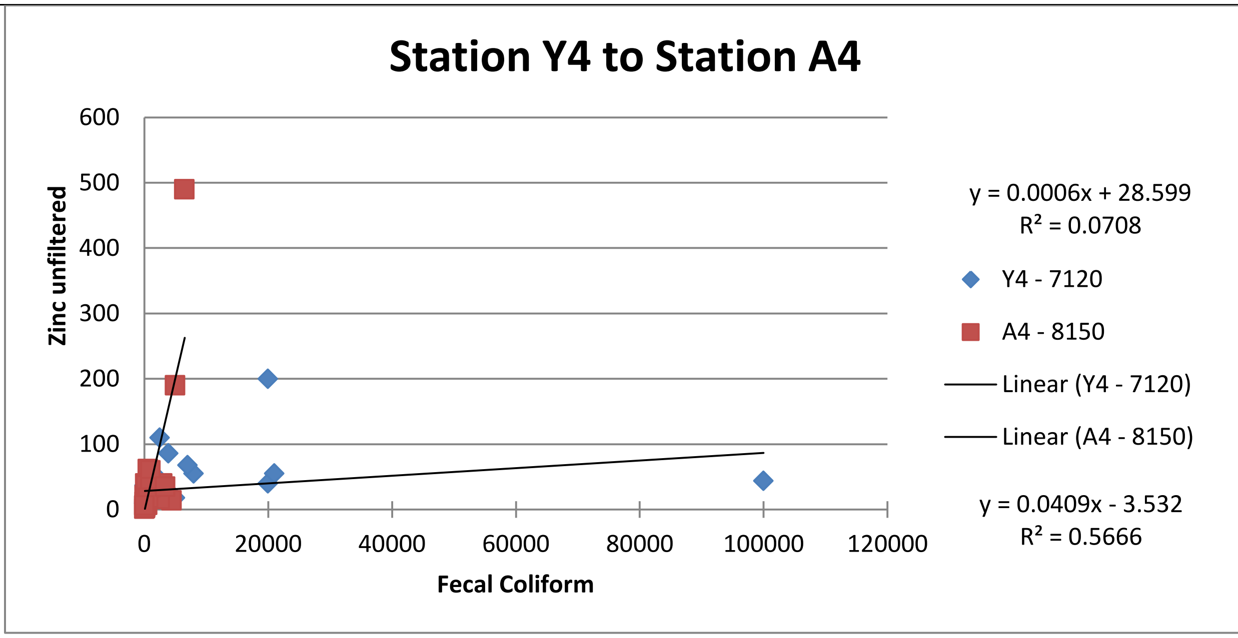

Figure 14. Relationship of Zinc to fecal coliform at the Yellow River Station 4 and the Alcovy River station 4.

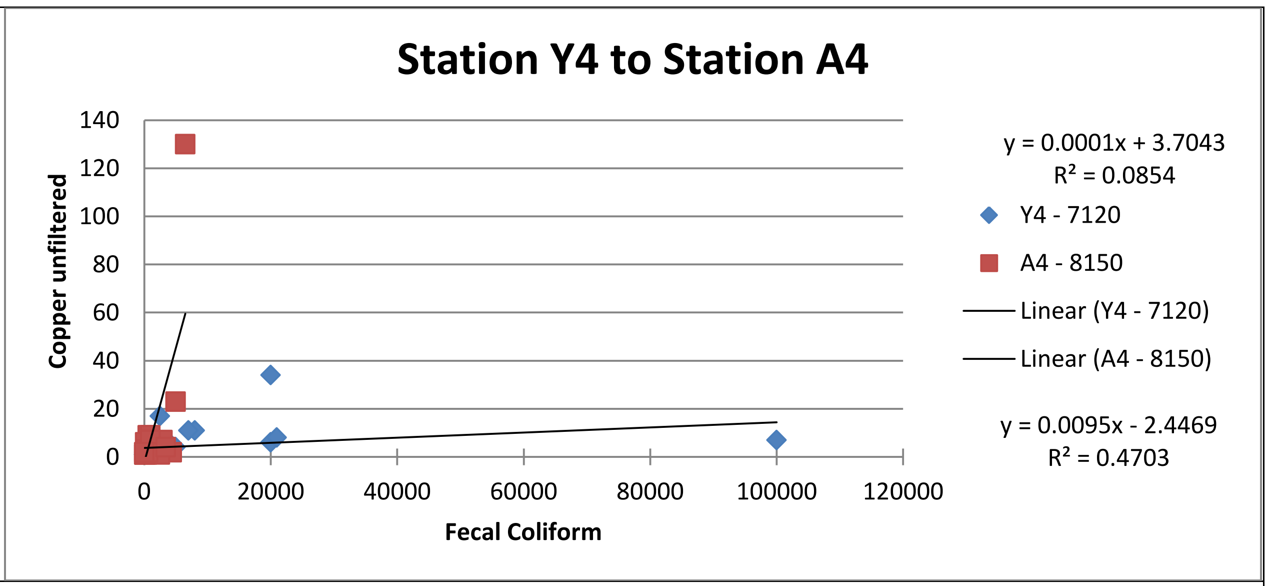

Figure 15. Relationship of Copper to fecal coliform at the Yellow River Station 4 and the Alcovy River station 4.

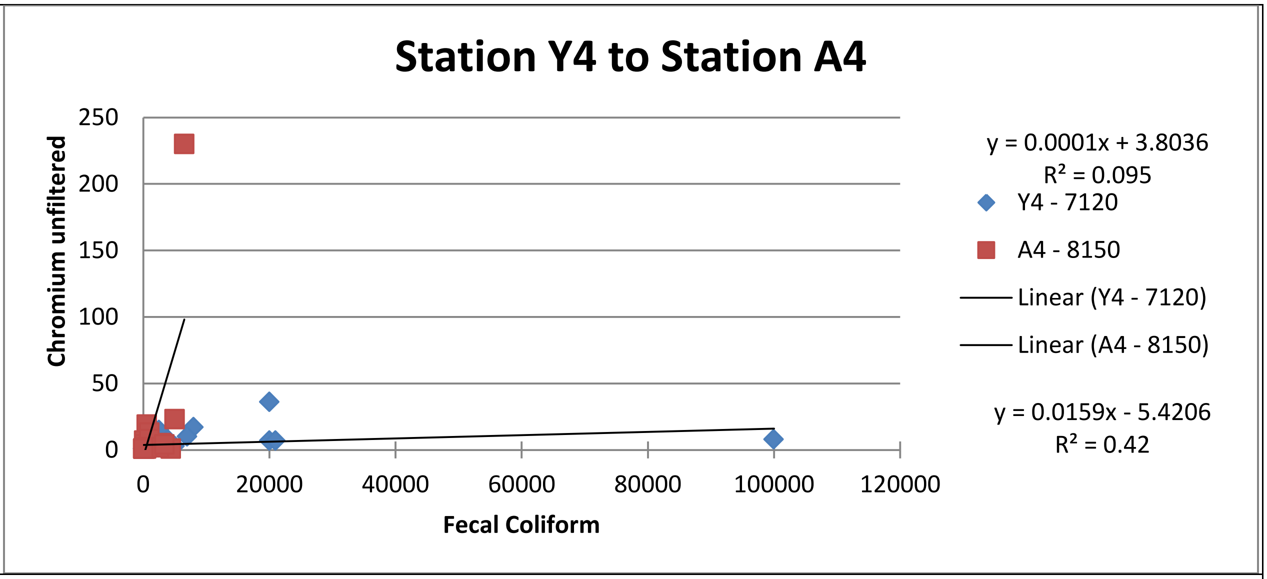

Figure 16. Relationship of Chromium to fecal coliform at the Yellow River Station 4 and the Alcovy River station 4.

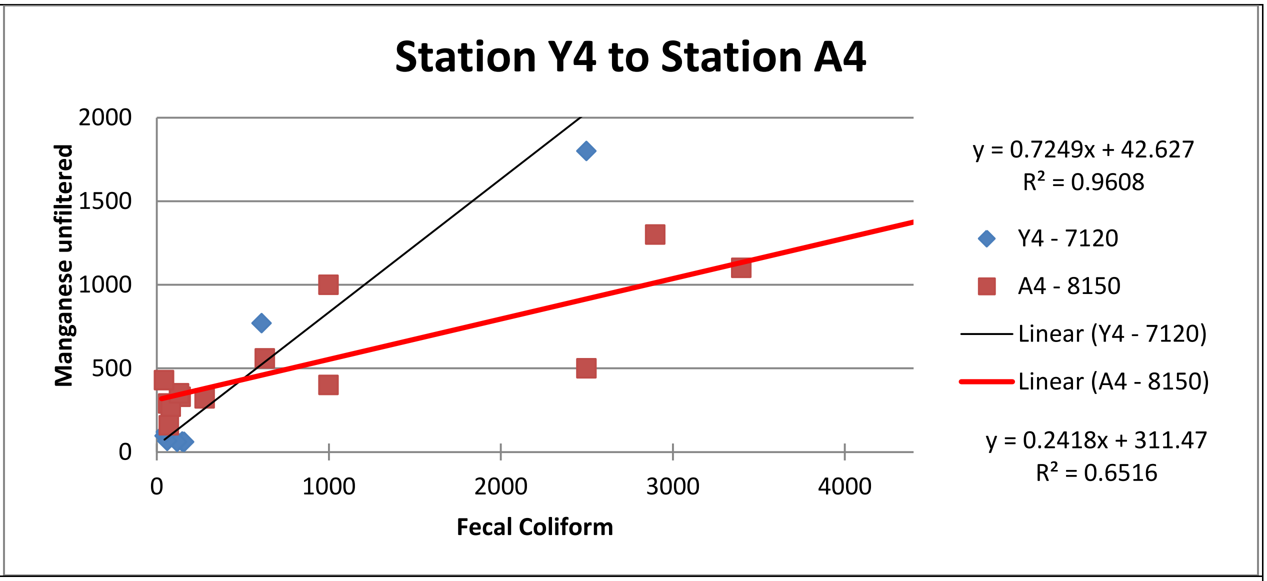

Figure 17. Relationship of Manganese to fecal coliform at the Yellow River Station 4 and the Alcovy River station 4.

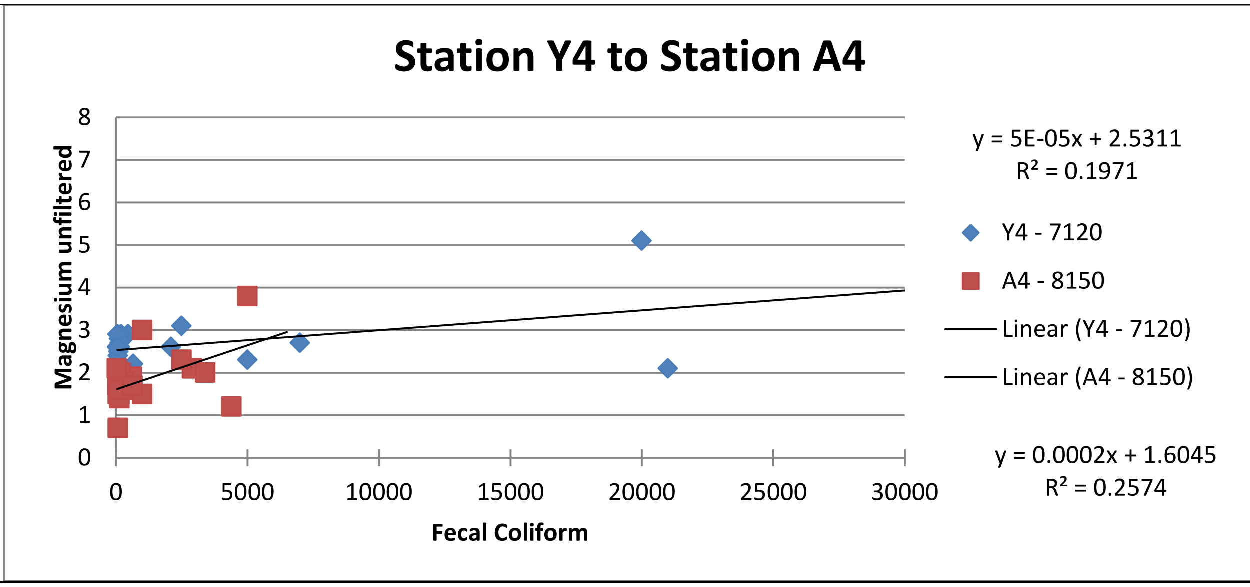

Figure 18. Relationship of Magnesium to fecal coliform at the Yellow River Station 4 and the Alcovy River station 4.

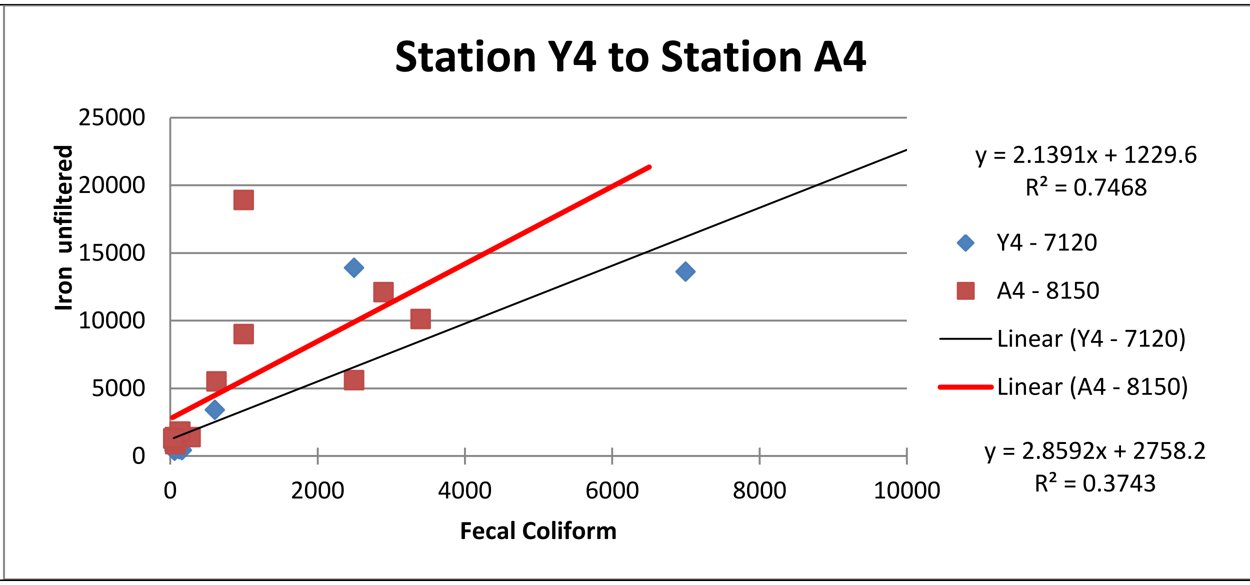

Figure 19. Relationship of Iron to fecal coliform at the Yellow River Station 4 and the Alcovy River station 4.

There were several nutrient parameters measured within the surface water at the Yellow River Station 4 and the Alcovy River Station 4. These nutrient parameters are Ammonia plus organic nitrogen, Total Nitrogen plus nitrate, Total Nitrogen, and Phosphorus. The relationship of these nutrient parameters to fecal coliform are shown in Figures 20 through 23. Besides these nutrient parameters there are parameters that are related to the introduction of biological organisms into the surface water mainly in the form of fecal coliform or *E. coli*. These parameters that indicate the presence of biological organisms within the water are the biochemical oxygen demand, the chemical oxygen demand, dissolved oxygen, and the total coliform. The relationships of these parameters to fecal coliform are represented in Figures 24 through 27.

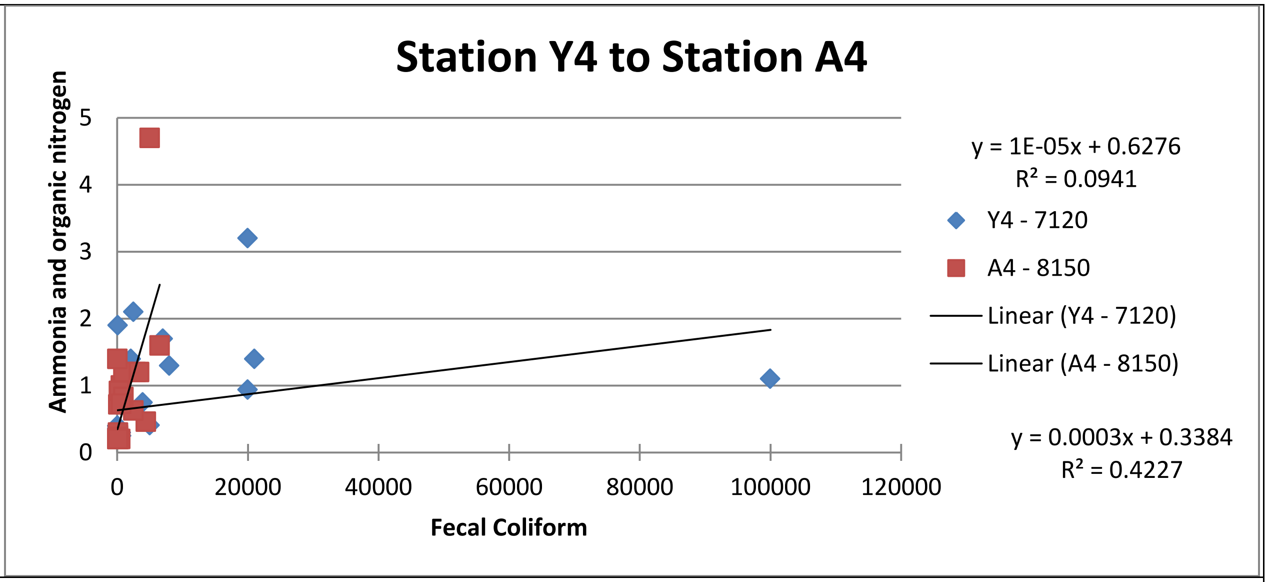

Figure 20. Relationship of Ammonia plus organic nitrogen to fecal coliform at the Yellow River Station 4 and the Alcovy River station 4.

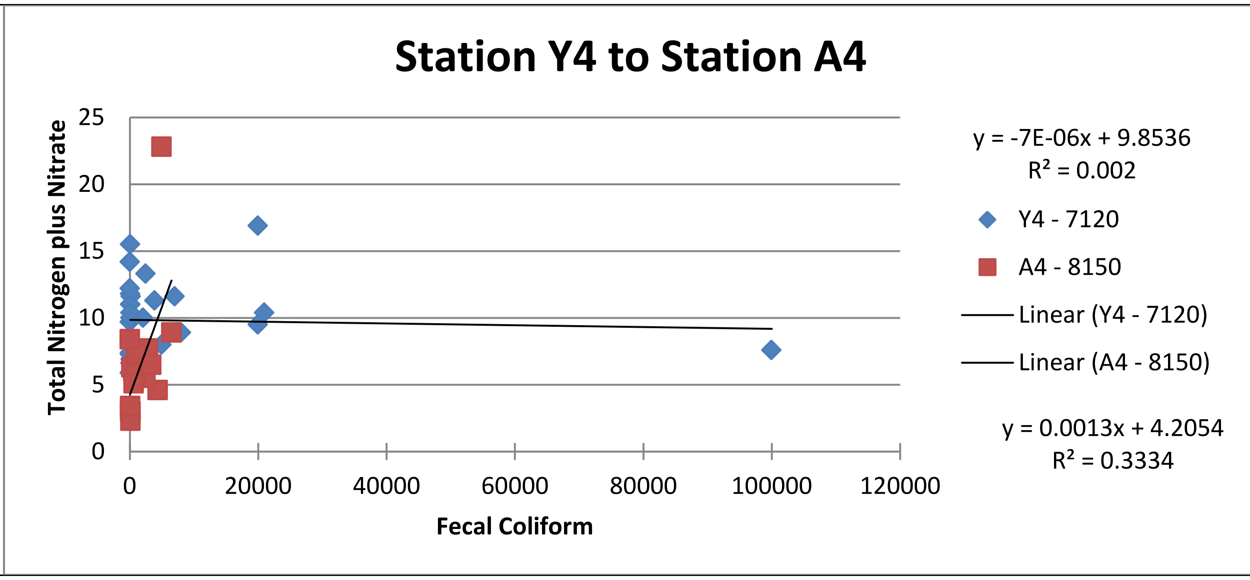

Figure 21. Relationship of Total Nitrogen plus nitrate to fecal coliform at the Yellow River Station 4 and the Alcovy River station 4.

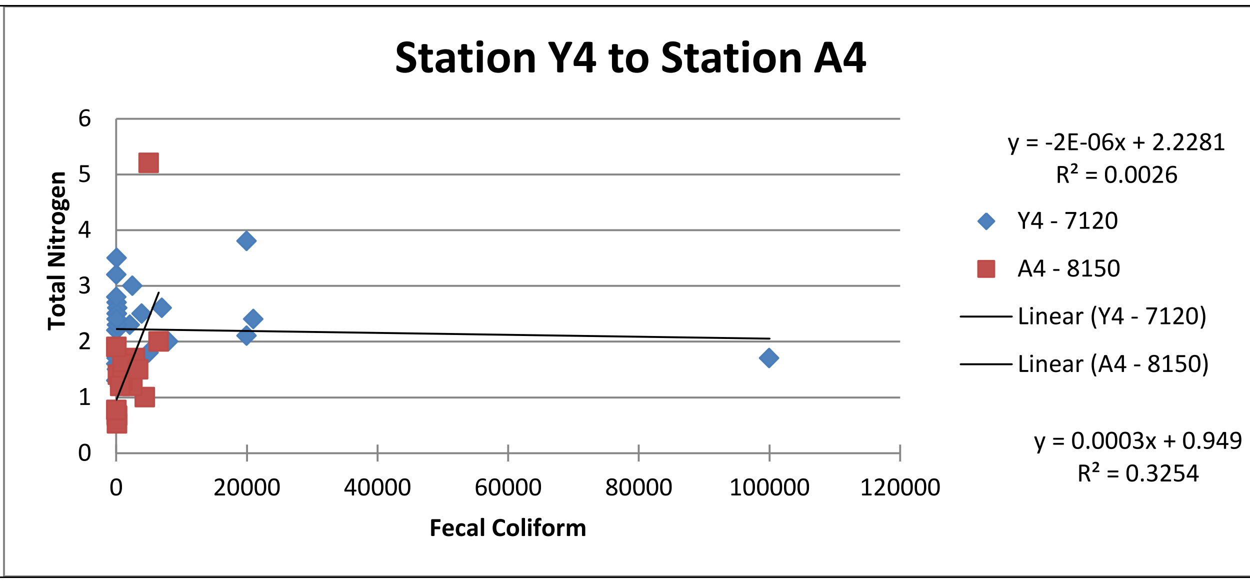

Figure 22. Relationship of Total Nitrogen to fecal coliform at the Yellow River Station 4 and the Alcovy River station 4.

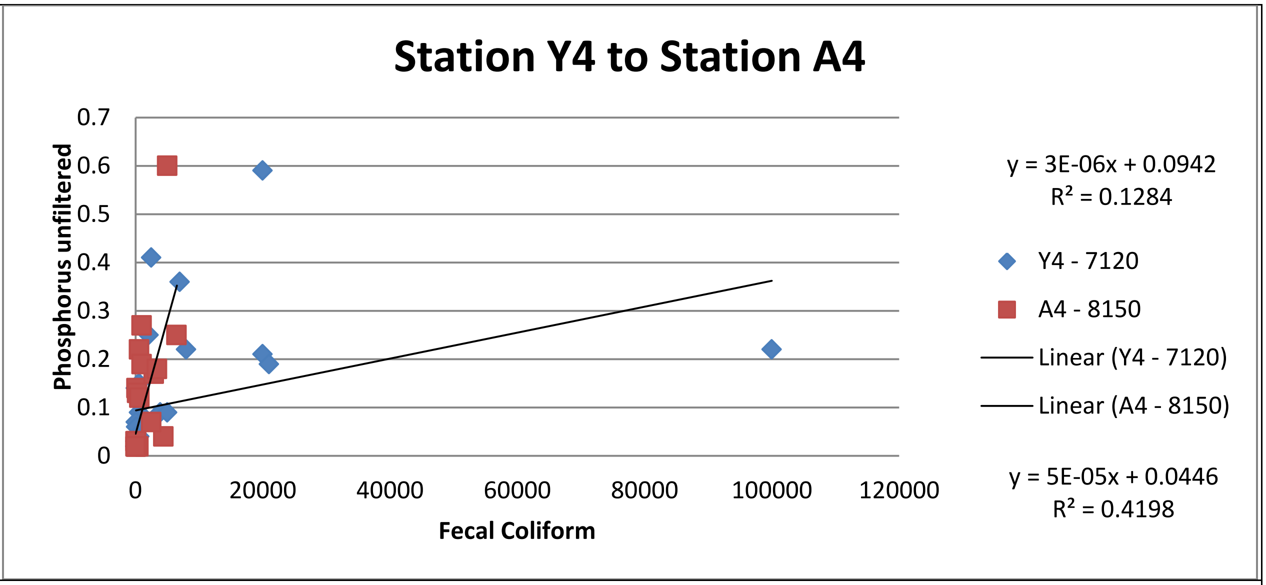

Figure 23. Relationship of Phosphorus to fecal coliform at the Yellow River Station 4 and the Alcovy River station 4.

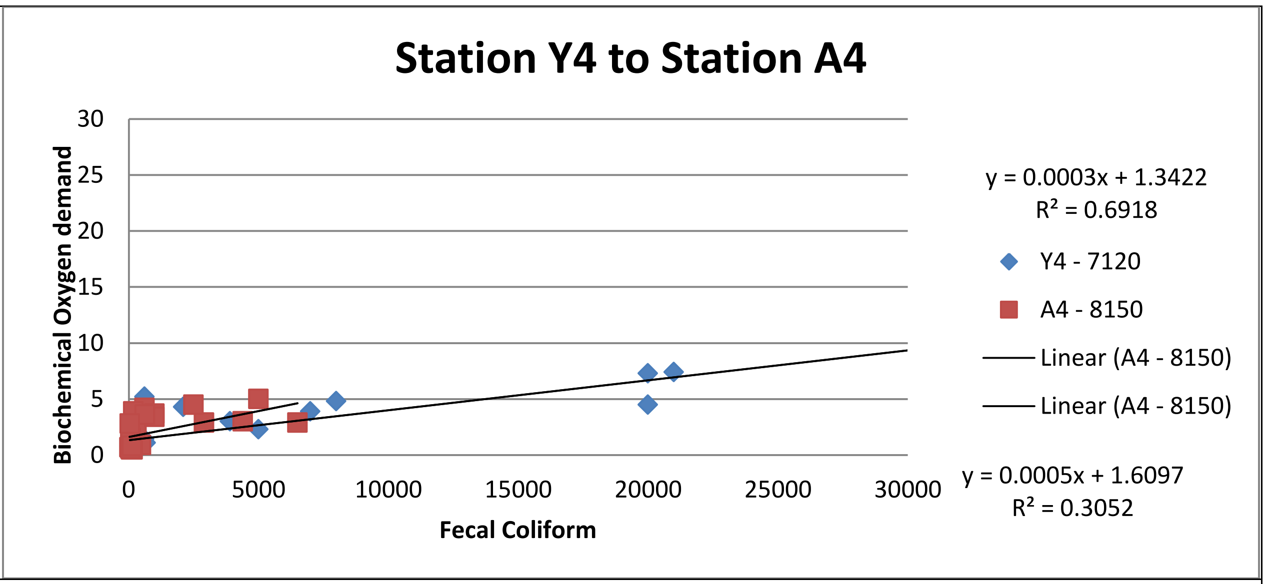

Figure 24. Relationship of Biochemical Oxygen Demand to fecal coliform at the Yellow River Station 4 and the Alcovy River station 4.

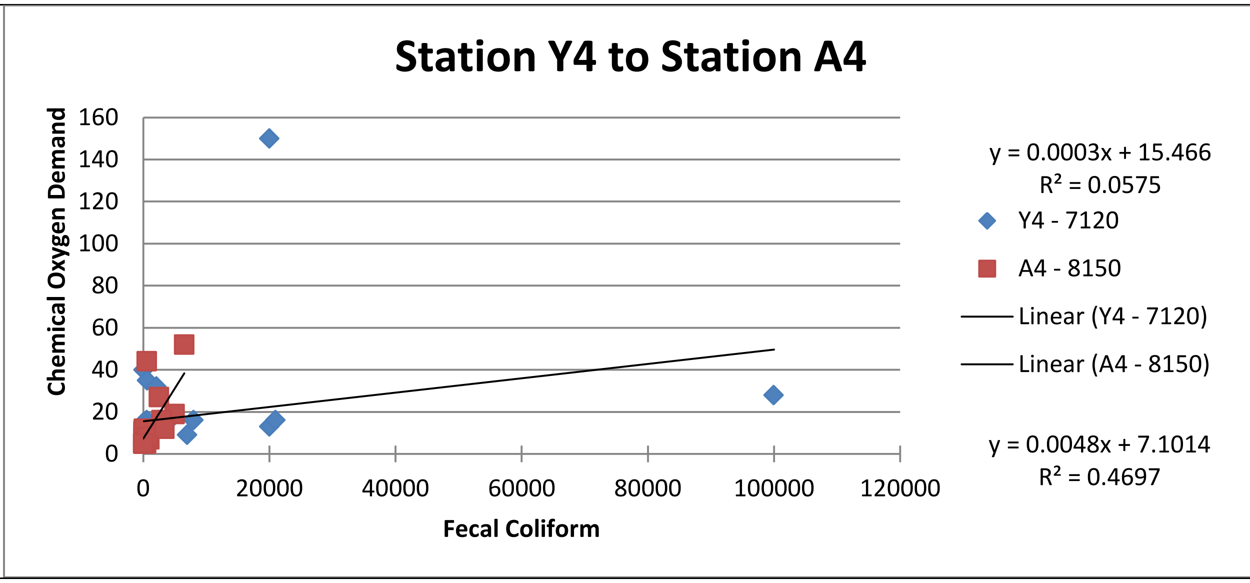

Figure 25. Relationship of Chemical Oxygen Demand to fecal coliform at the Yellow River Station 4 and the Alcovy River station 4.

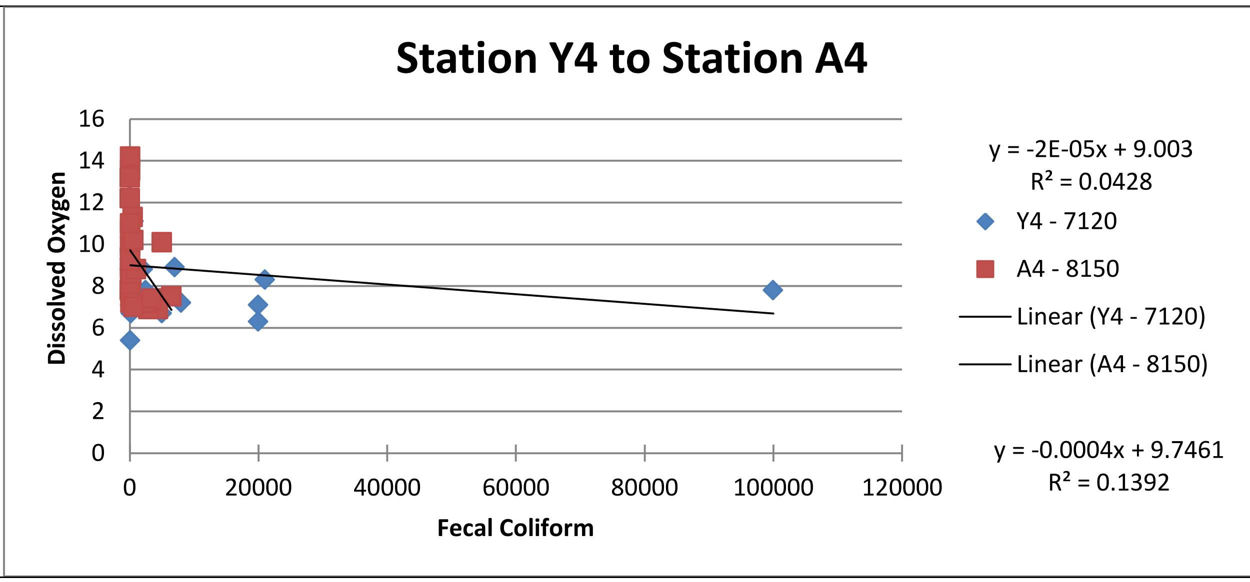

Figure 26. Relationship of Dissolved Oxygen to fecal coliform at the Yellow River Station 4 and the Alcovy River station 4.

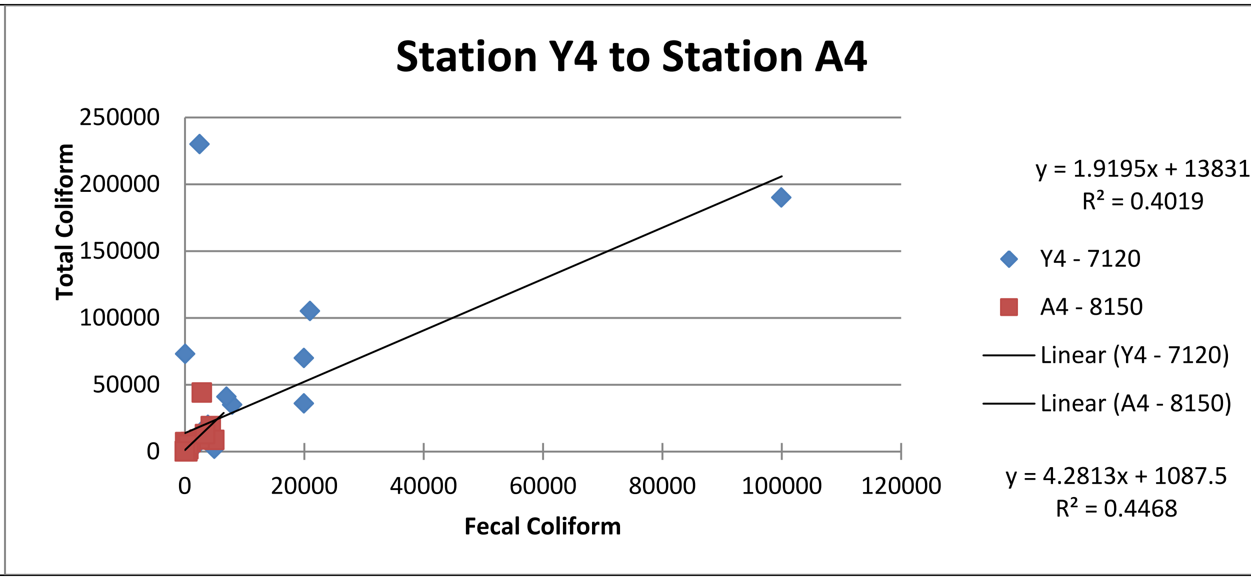

Figure 27. Relationship of Total Coliform to fecal coliform at the Yellow River Station 4 and the Alcovy River station 4.

Other parameters from the Yellow River station 4 and Alcovy River station 4 that show significant correlation with fecal coliform are Suspended solids, Turbidity, Specific conductance, hydrogen ion concentration, water temperature, and pH (measured in the field). Figures 28 through 33 show the graphs of these parameters in relationship with fecal coliform.

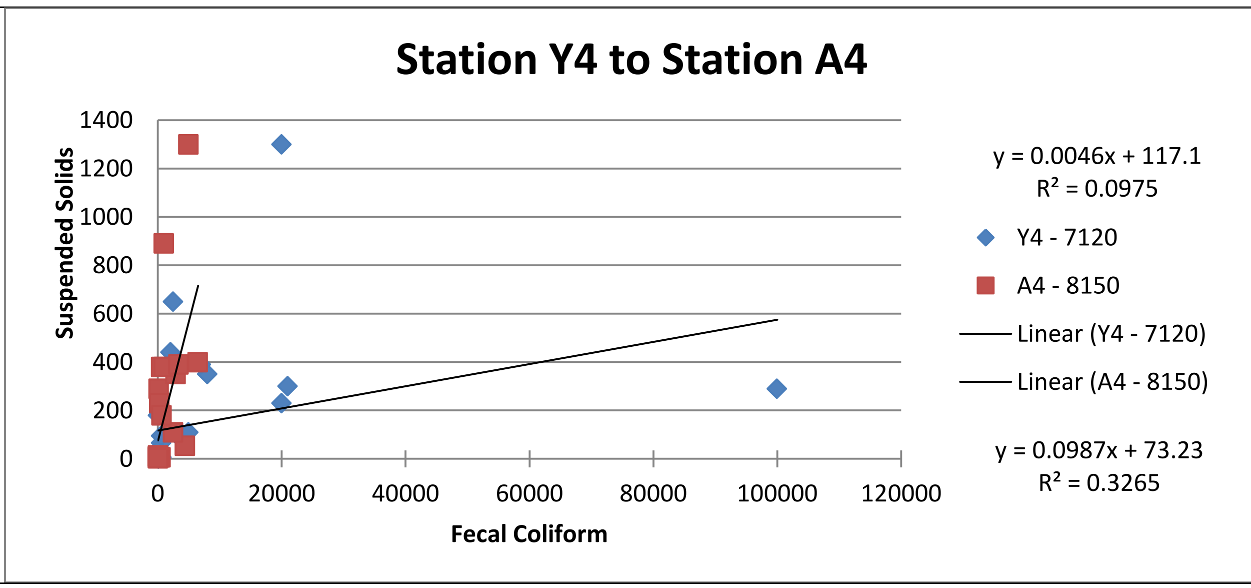

Figure 28. Relationship of Suspended Solids to fecal coliform at the Yellow River Station 4 and the Alcovy River station 4.

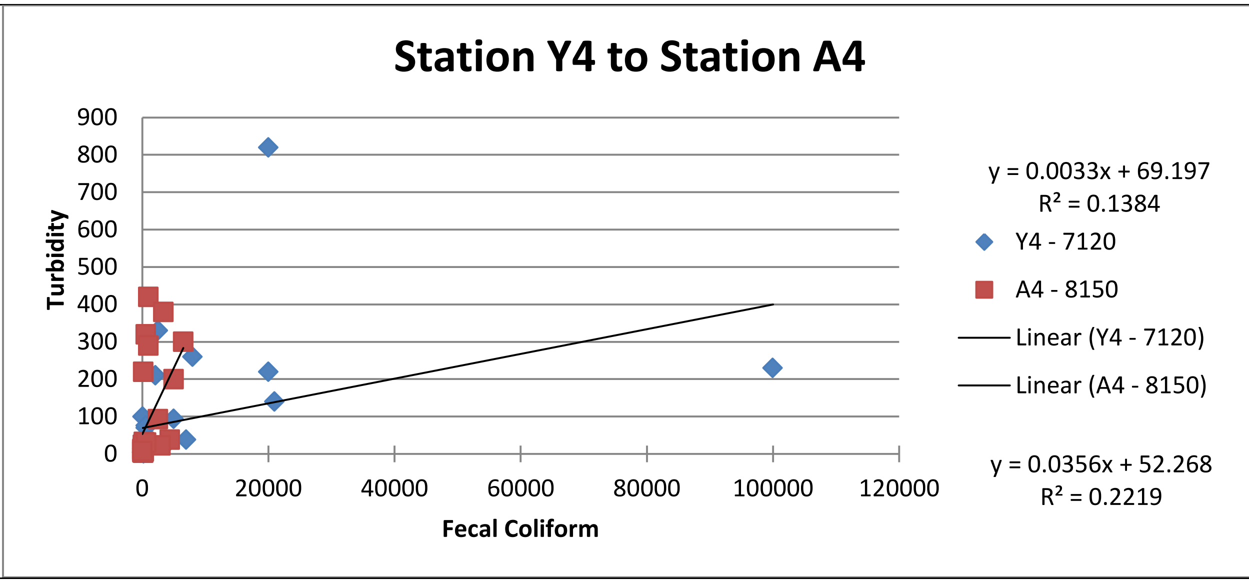

Figure 29. Relationship of Turbidity to fecal coliform at the Yellow River Station 4 and the Alcovy River station 4.

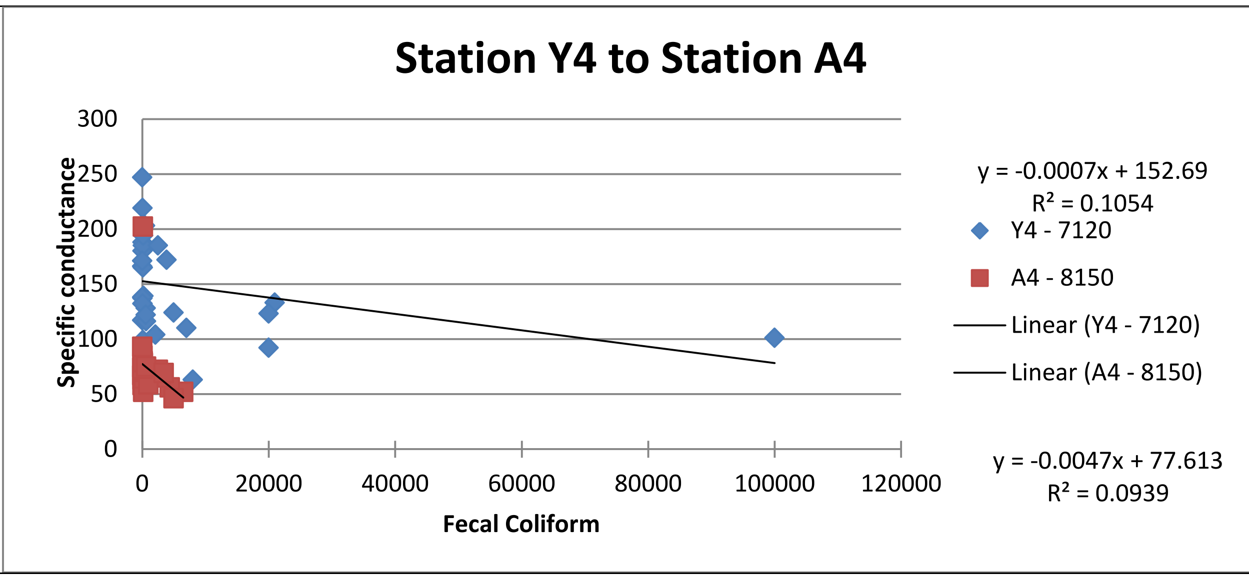

Figure 30. Relationship of Specific Conductance to fecal coliform at the Yellow River Station 4 and the Alcovy River station 4.

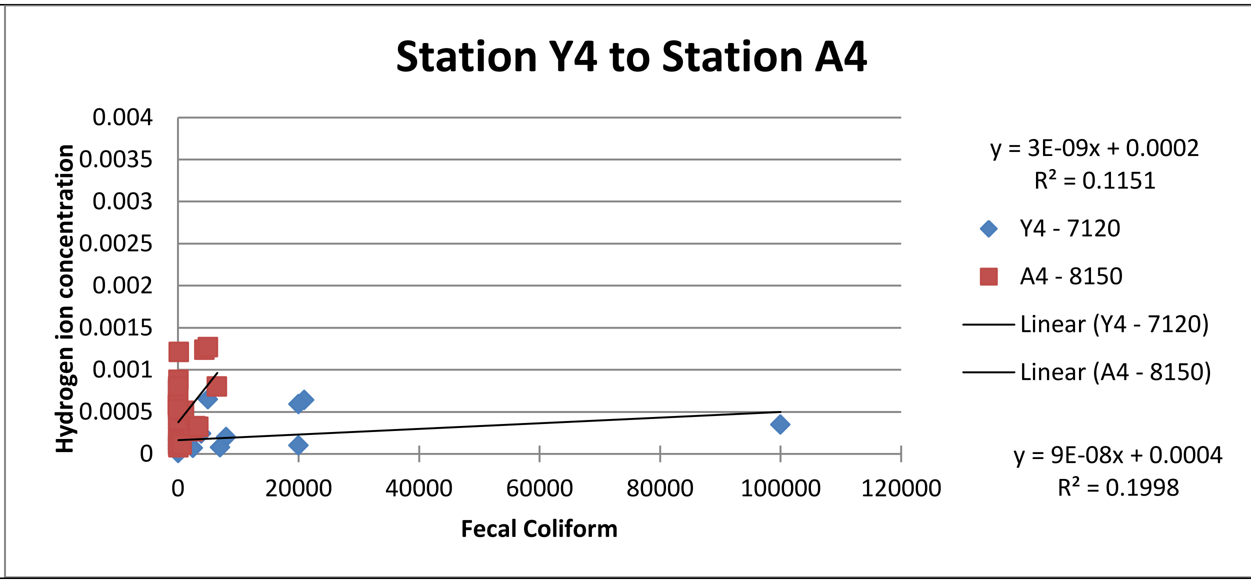

Figure 31. Relationship of Hydrogen Ion Concentration to fecal coliform at the Yellow River Station 4 and the Alcovy River station 4.

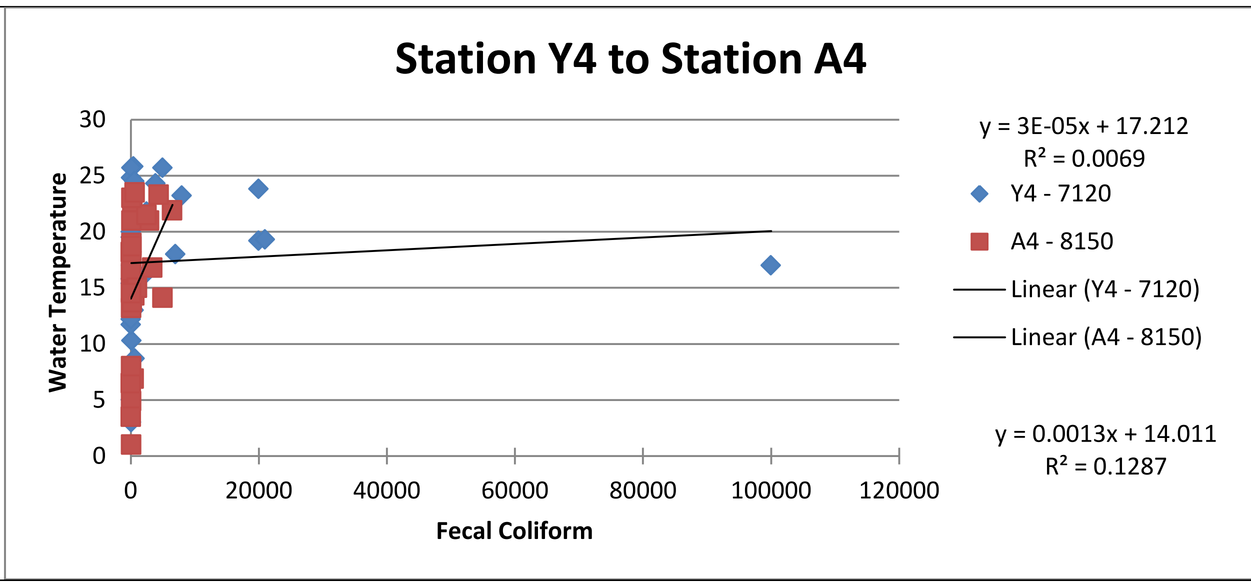

Figure 32. Relationship of Water Temperature to fecal coliform at the Yellow River Station 4 and the Alcovy River station 4.

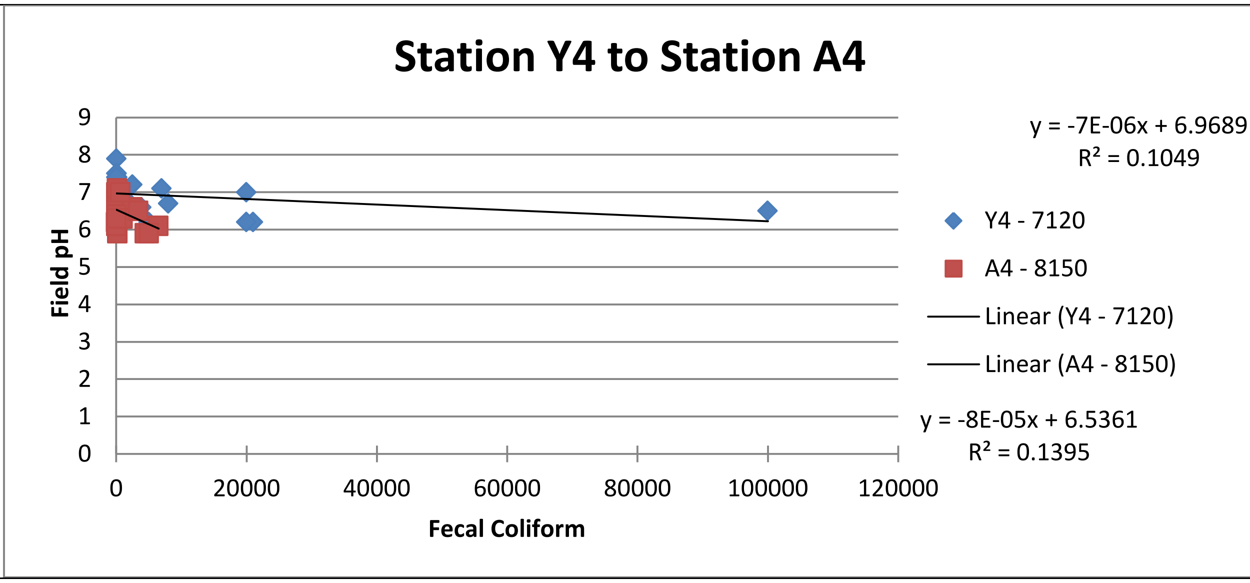

Figure 33. Relationship of pH (measured in the field) to fecal coliform at the Yellow River Station 4 and the Alcovy River station 4.

There are some relationships between the amount of rainfall and the amount of fecal coliform found in the surface water for the two localities within the Yellow River and Alcovy River basins, stations Y4 and A4. The relationship with the best fit linear regression line is for the amount of rain on the day of the water quality reading. This is shown in Figure 34 below.

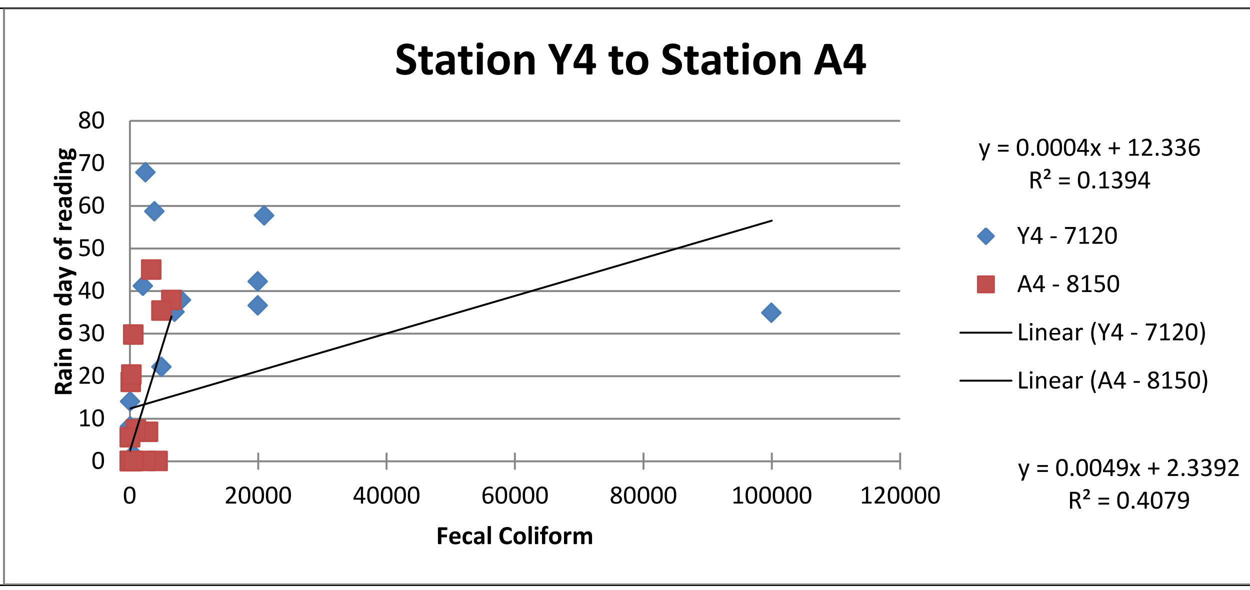

Figure 34. The relationship between fecal coliform and the amount of rain that occurs on the day the water quality reading was taken.

Other relationships that were compared were the number of days of rain 7 days prior to the reading, the amount of rainfall per day prior to the water quality reading, and the number of days of rainfall 4 week prior to the water quality reading. The relationships are shown in Figures 35 through 37.

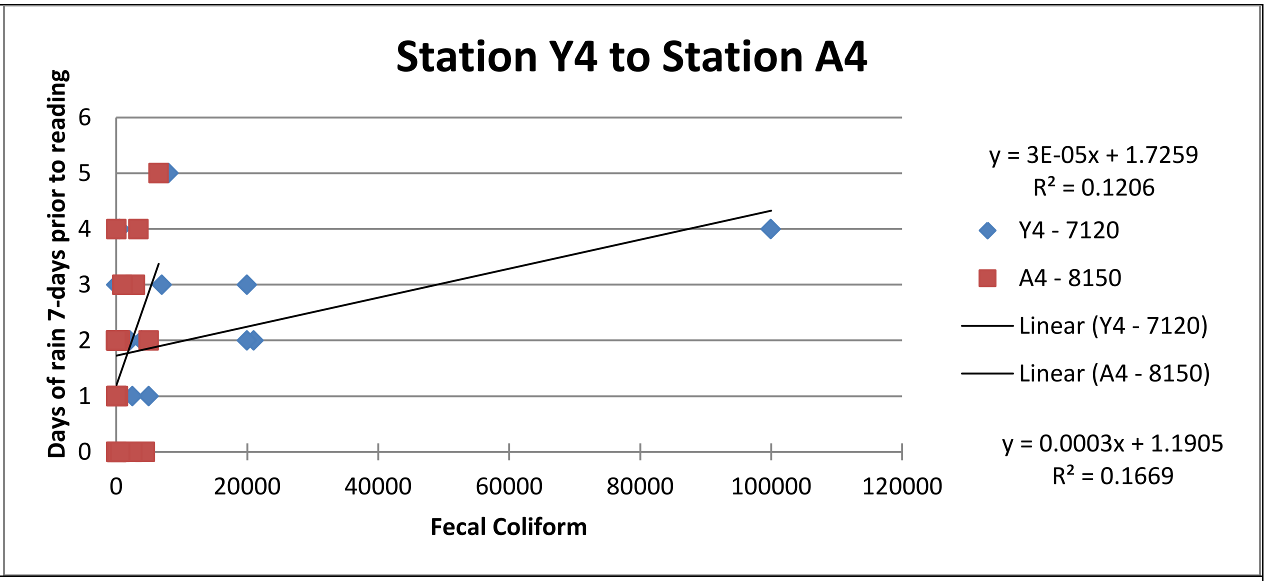

Figure 35. The relationship between fecal coliform and the number of days of rain 7 days prior to the water quality reading was taken.

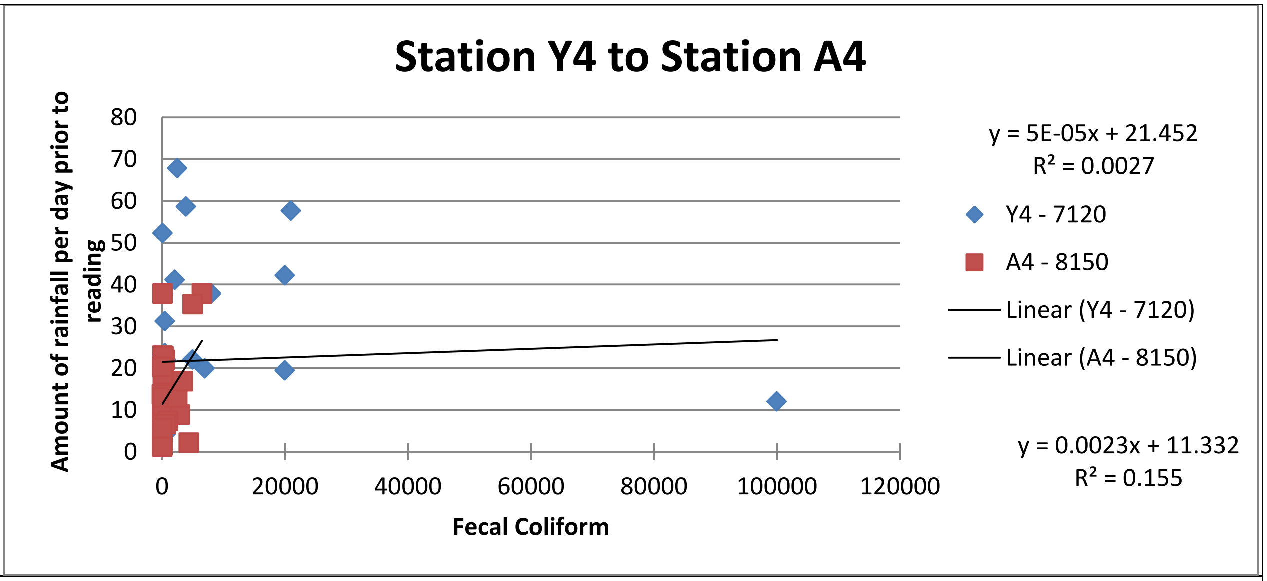

Figure 36. The relationship between fecal coliform and the amount of rainfall per day prior to the water quality reading.

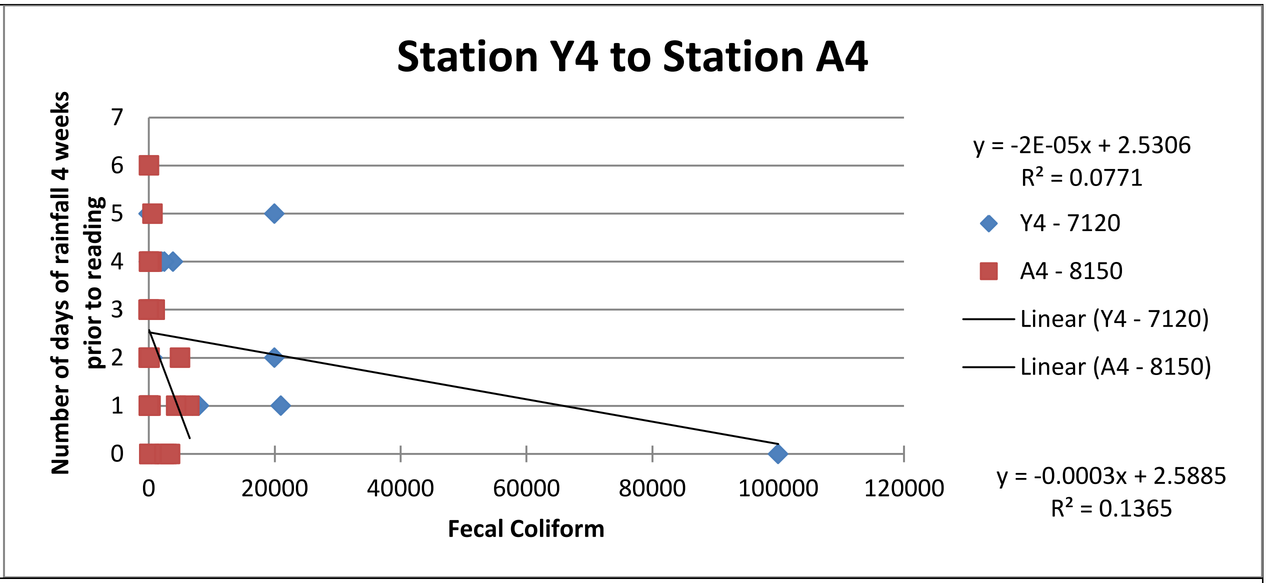

Figure 37. The relationship between fecal coliform and the number of days of rainfall 4 week prior to the water quality reading.

There were several other relationships between fecal coliform and the amount and duration of the rainfall prior to the water quality readings being taken. They all had varying degrees of correlation with fecal coliform. The relationship between the amount of rainfall 7 days prior, 14 days prior, 21 days prior and 28 days prior to the water quality measurement were looked at to see if there could be observed a distinct relationship with the amount of fecal coliform found within the surface water. Figures 38 through 41 show these relationships for stations Y4 and A4.

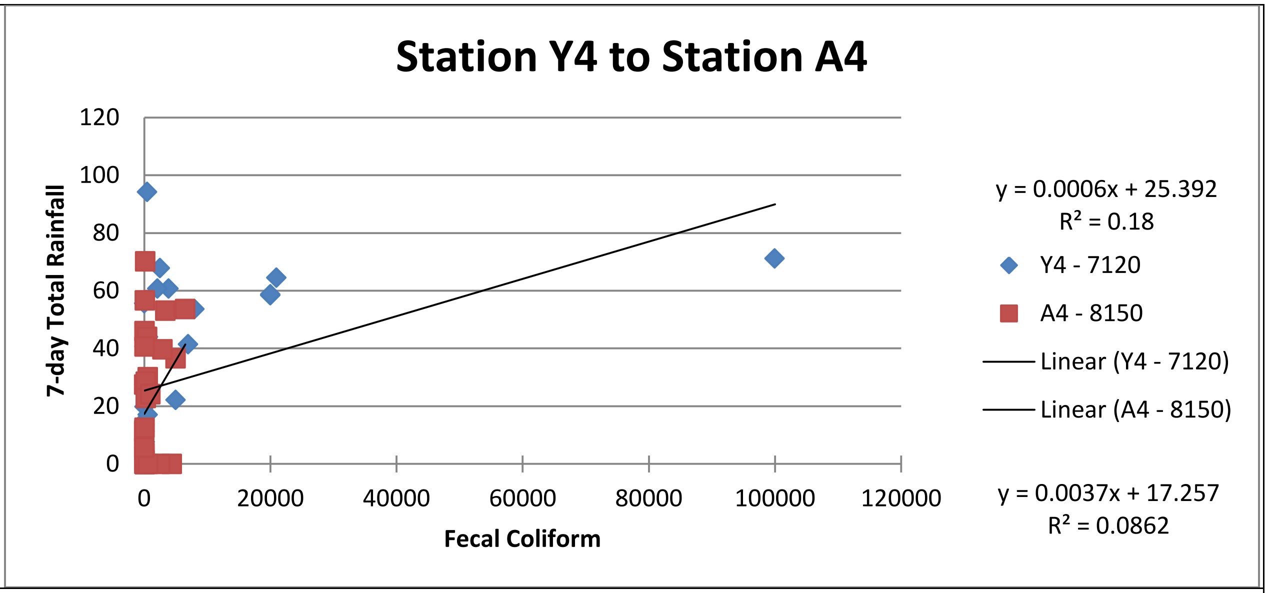

Figure 38. The relationship between the amount of rainfall 7 days prior to the water quality measurement and fecal coliform.

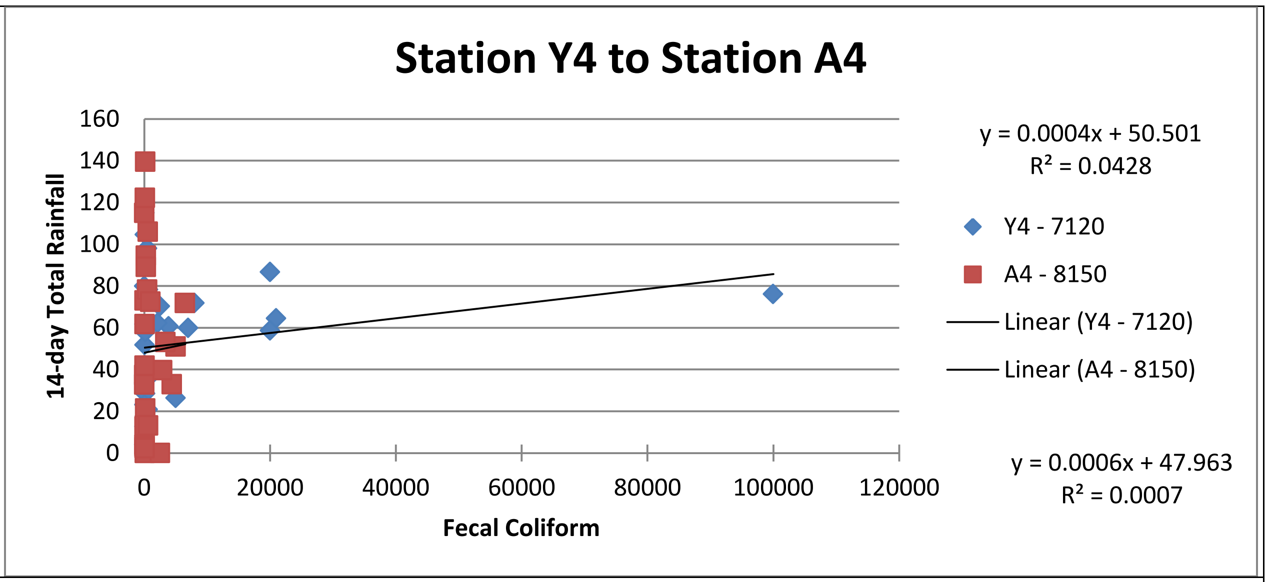

Figure 39. The relationship between the amount of rainfall 14 days prior to the water quality measurement and fecal coliform.

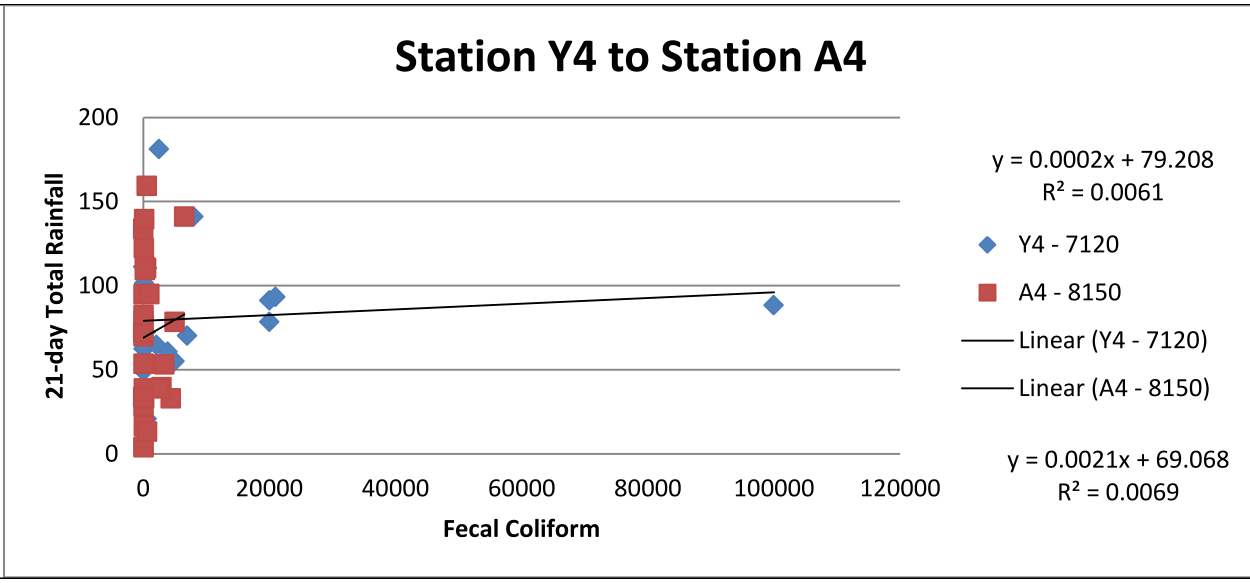

Figure 40. The relationship between the amount of rainfall 21 days prior to the water quality measurement and fecal coliform.

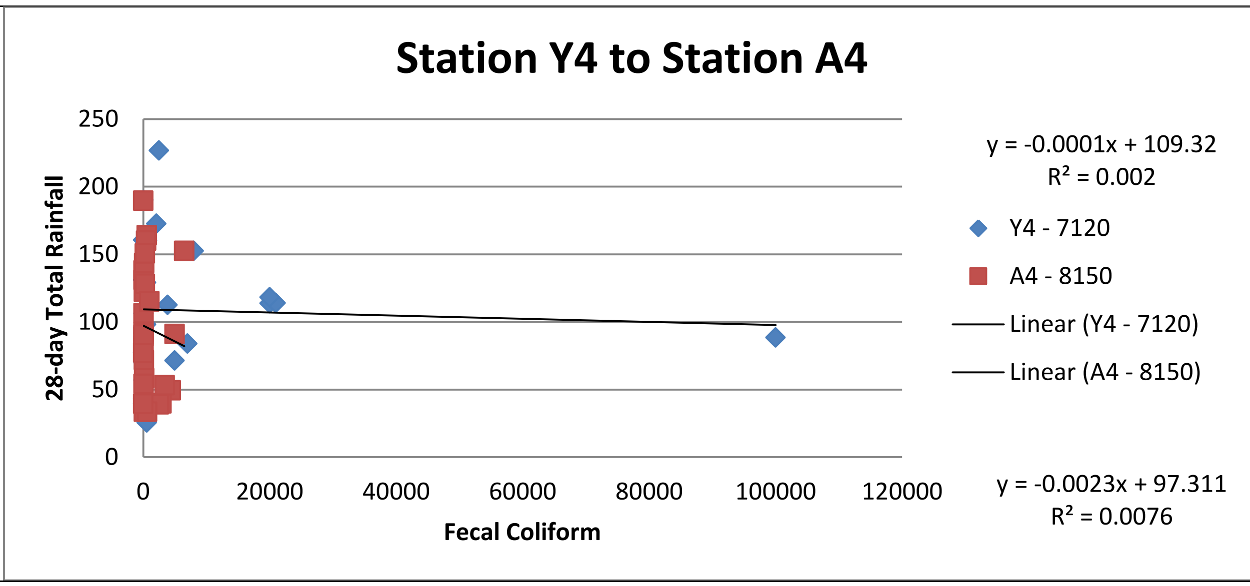

Figure 41. The relationship between the amount of rainfall 28 days prior to the water quality measurement and fecal coliform.

The last relationship observed for stations Y4 and A4 is with the gage height of the water at the water monitoring station and its relationship to fecal coliform. Only one of the graphs is shown, the one for the gage height in feet. The graph for the gage height in meters is the same graph just with the unit of meters. Figure 42 shows this relationship for the gage height.

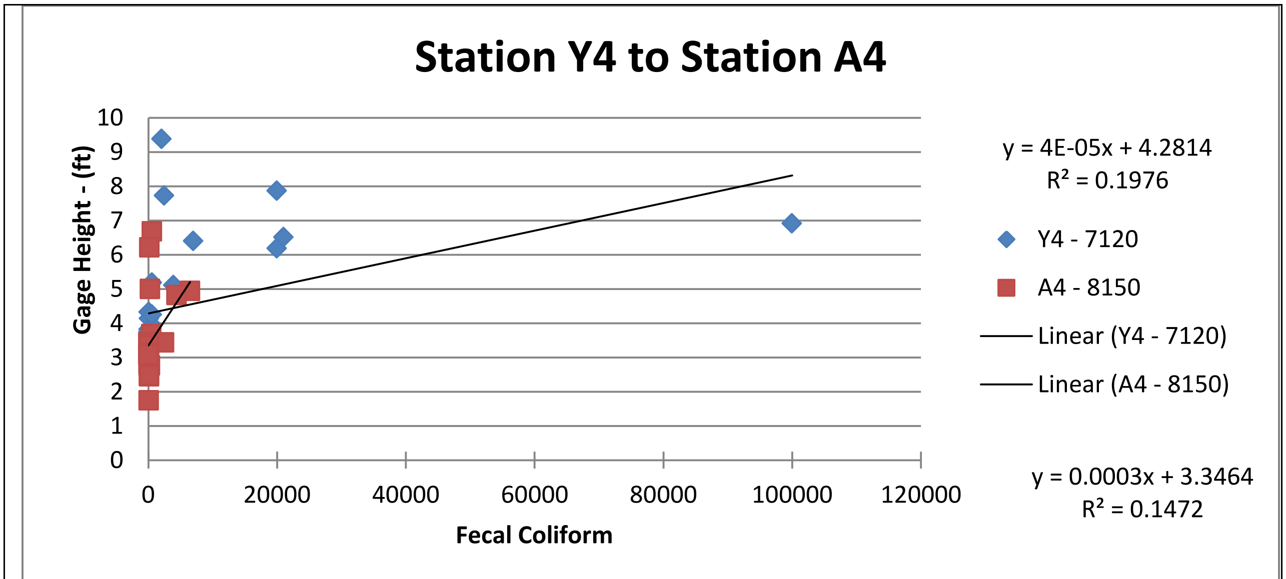

Figure 42. Relationship of gage height in feet to fecal coliform for the Yellow River basin station Y4 and the Alcovy River basin station A4 in Gwinnett County, GA.

There were similar relationships observed for the Yellow River basin station Y2 and the Alcovy River basin station A2 for the time frame of the years 2005 to 2010 for these two river basins. Relationships between total coliform, *E. coli*, Specific conductance, Water temperature, dissolved oxygen, the pH of the water taken in the field, turbidity, and the instantaneous discharge in feet with fecal coliform were observed to be significantly correlated. Linear regression lines were plotted for the scatter plots of these parameters and are shown in Figures 43 through 50.

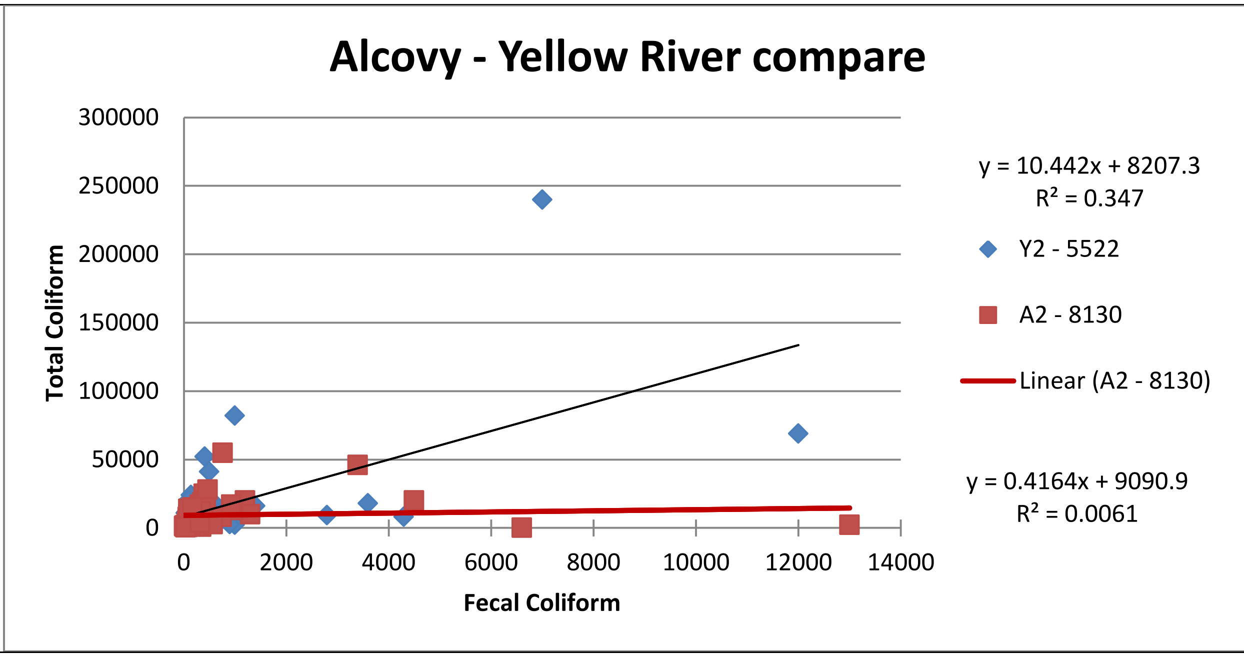

Figure 43. Scatter plot of fecal coliform with total coliform with linear regression lines for the Yellow River basin Station Y2 and the Alcovy River basin station A2.

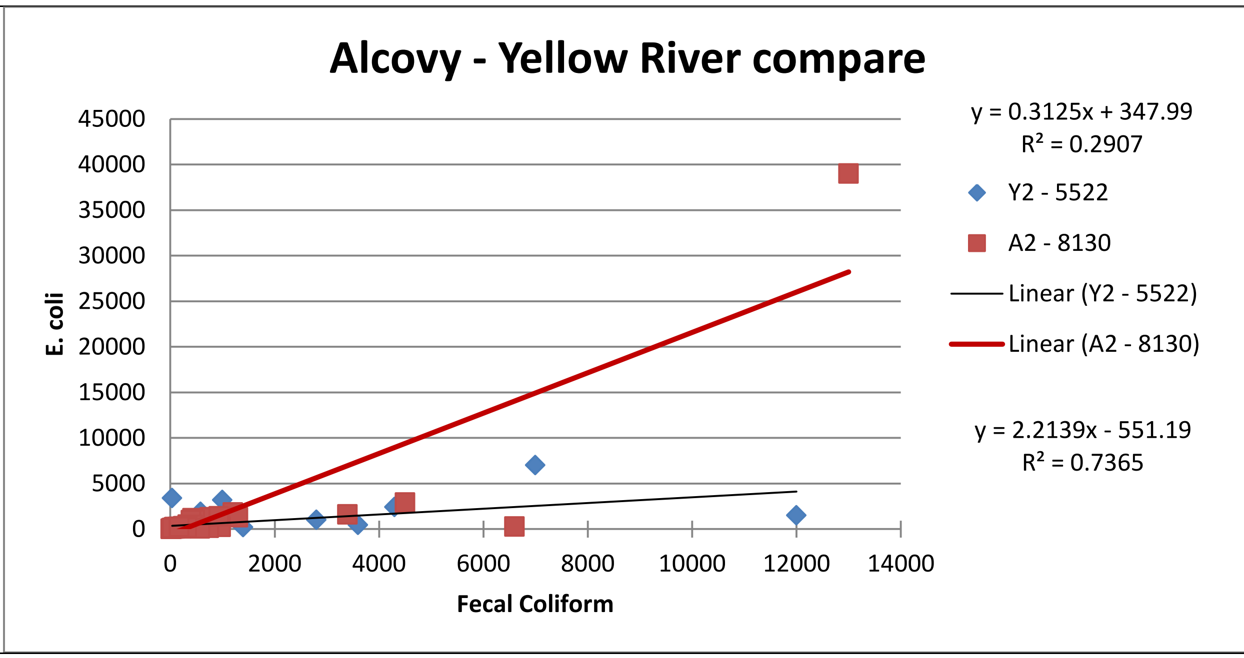

Figure 44. Scatter plot of fecal coliform with E. coli with linear regression lines for the Yellow River basin Station Y2 and the Alcovy River basin station A2.

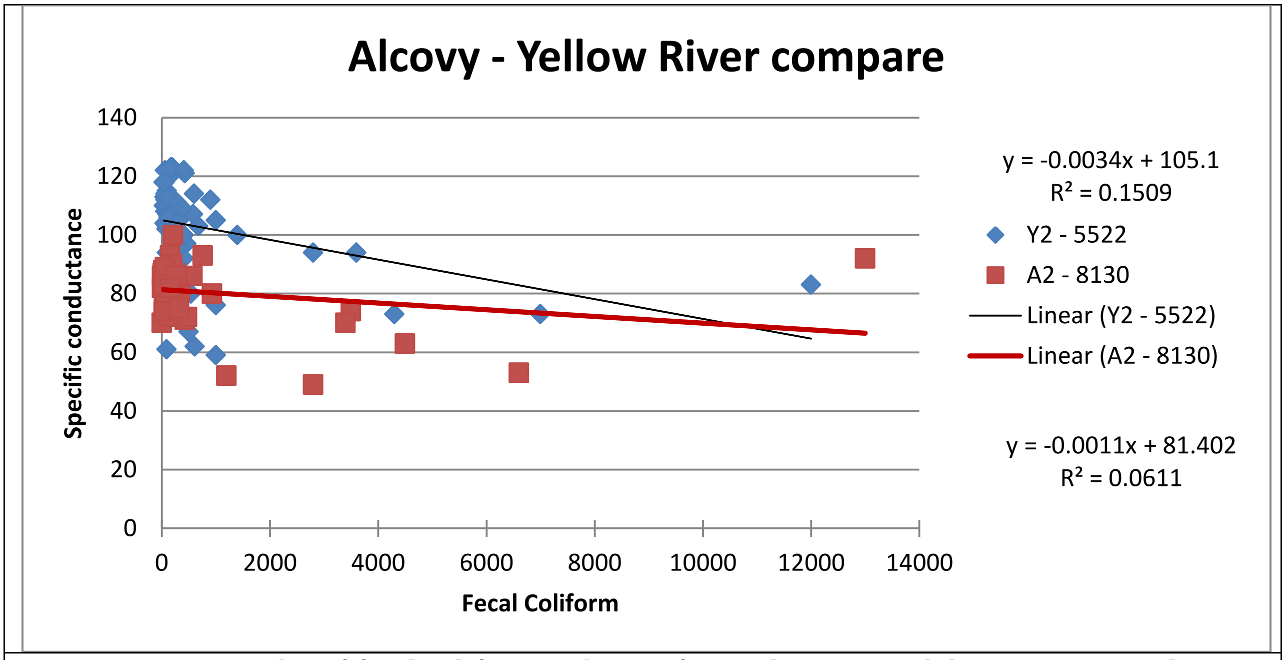

Figure 45. Scatter plot of fecal coliform with specific conductance with linear regression lines for the Yellow River basin Station Y2 and the Alcovy River basin station A2.

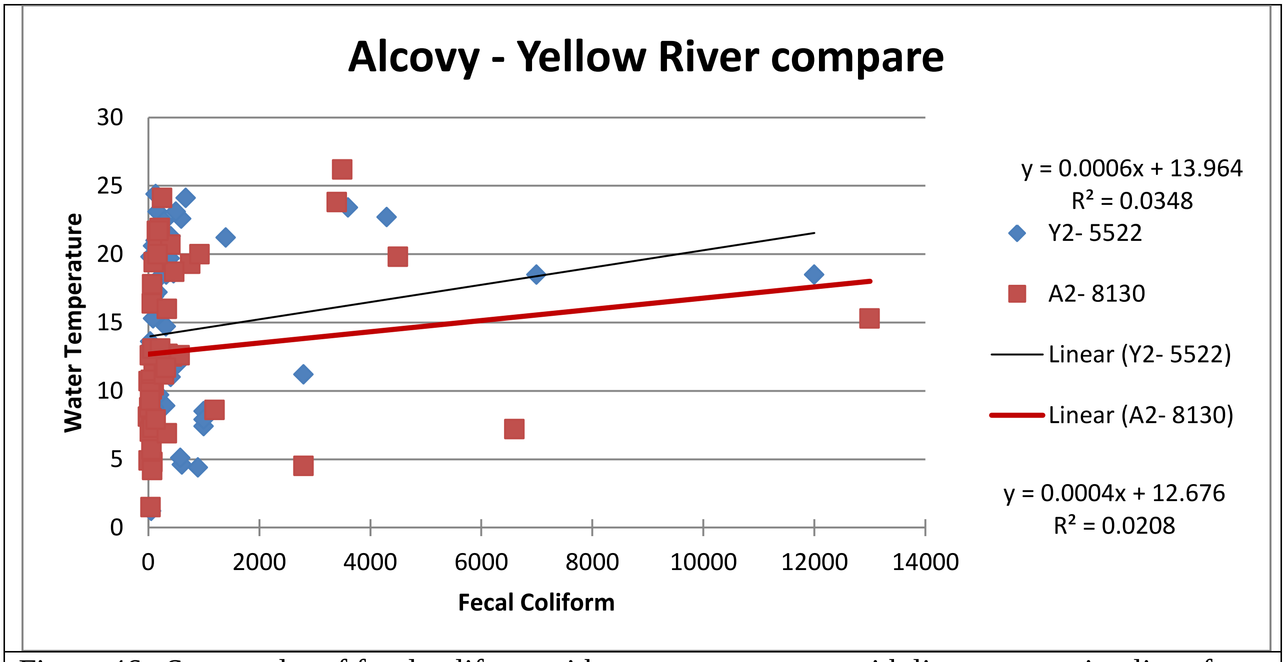

Figure 46. Scatter plot of fecal coliform with water temperature with linear regression lines for the Yellow River basin Station Y2 and the Alcovy River basin station A2.

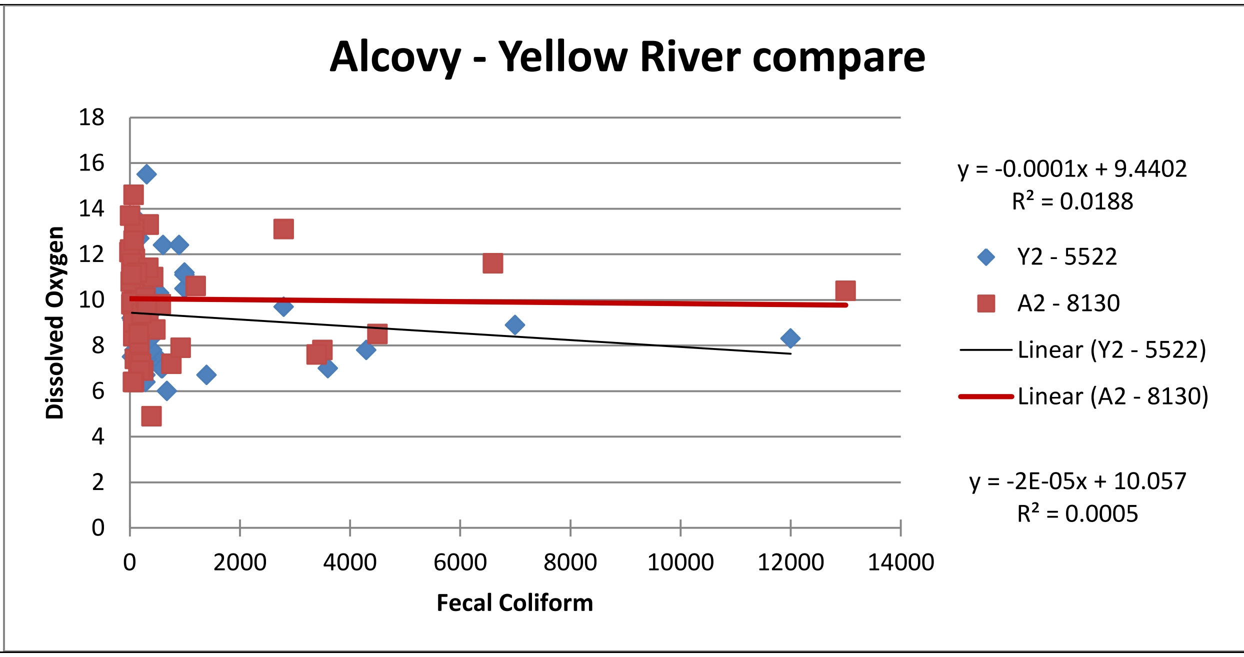

Figure 47. Scatter plot of fecal coliform with dissolved oxygen with linear regression lines for the Yellow River basin Station Y2 and the Alcovy River basin station A2.

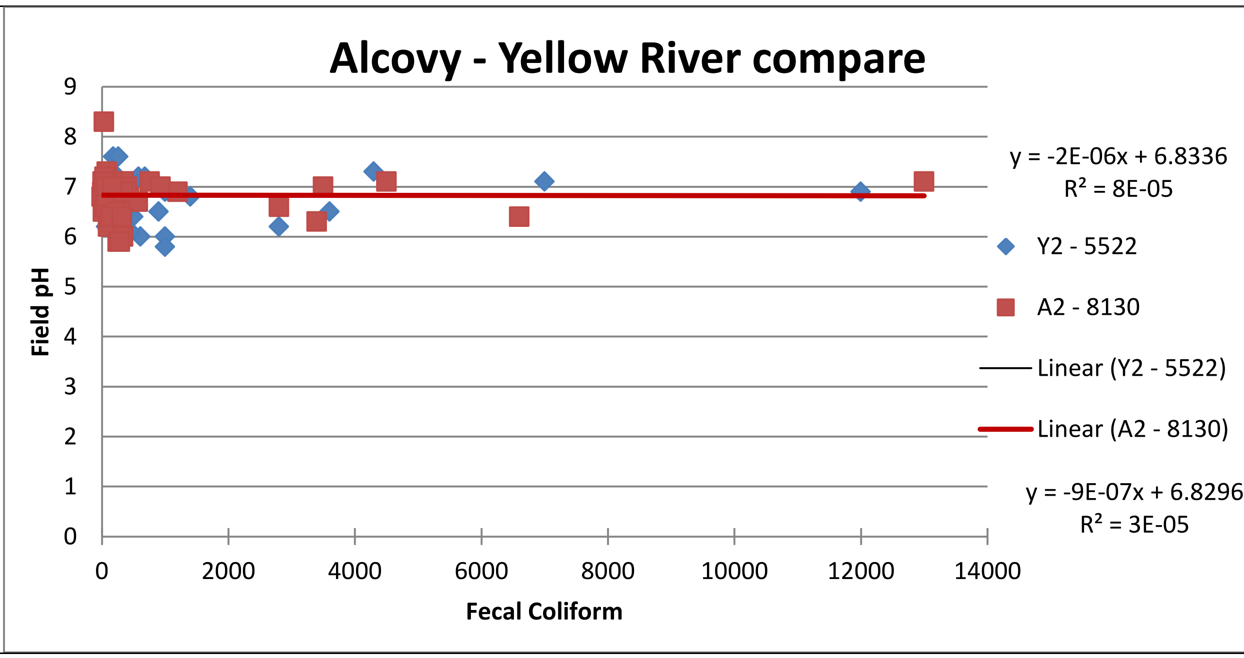

Figure 48. Scatter plot of fecal coliform with pH of the water measured in the field with linear regression lines for the Yellow River basin Station Y2 and the Alcovy River basin station A2.

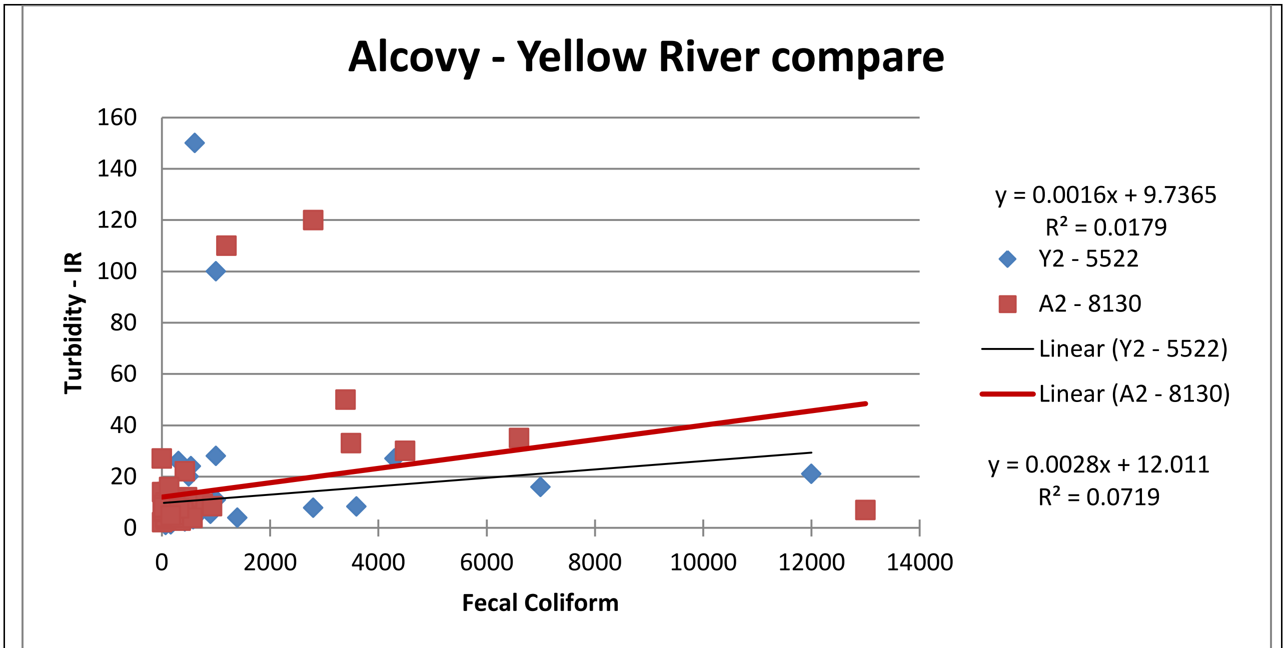

Figure 49. Scatter plot of fecal coliform with turbidity with linear regression lines for the Yellow River basin Station Y2 and the Alcovy River basin station A2.

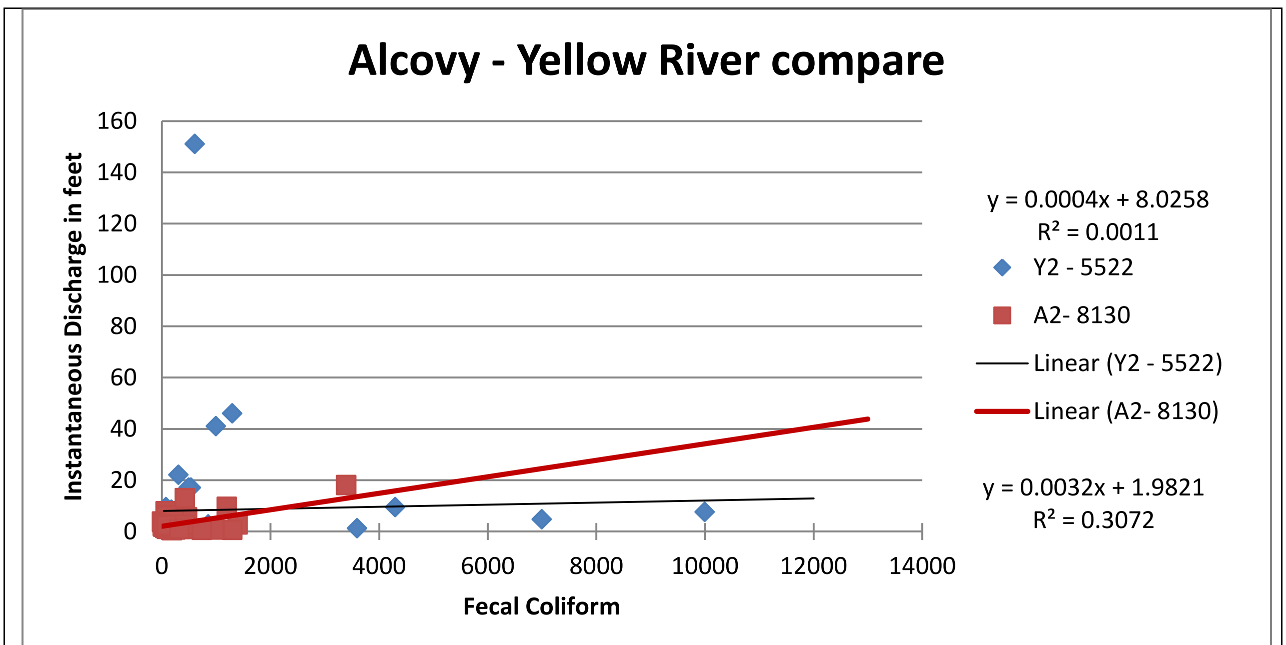

Figure 50. Scatter plot of fecal coliform with instantaneous discharge in feet with linear regression lines for the Yellow River basin Station Y2 and the Alcovy River basin station A2.

It was observed that there is a positive correlation between water temperature and fecal coliform. Figure 51 shows this relationship for Pew Creek in the Yellow River basin, station Y2. This trend is also observed in the other sub-basins of the Yellow and Alcovy River basins.

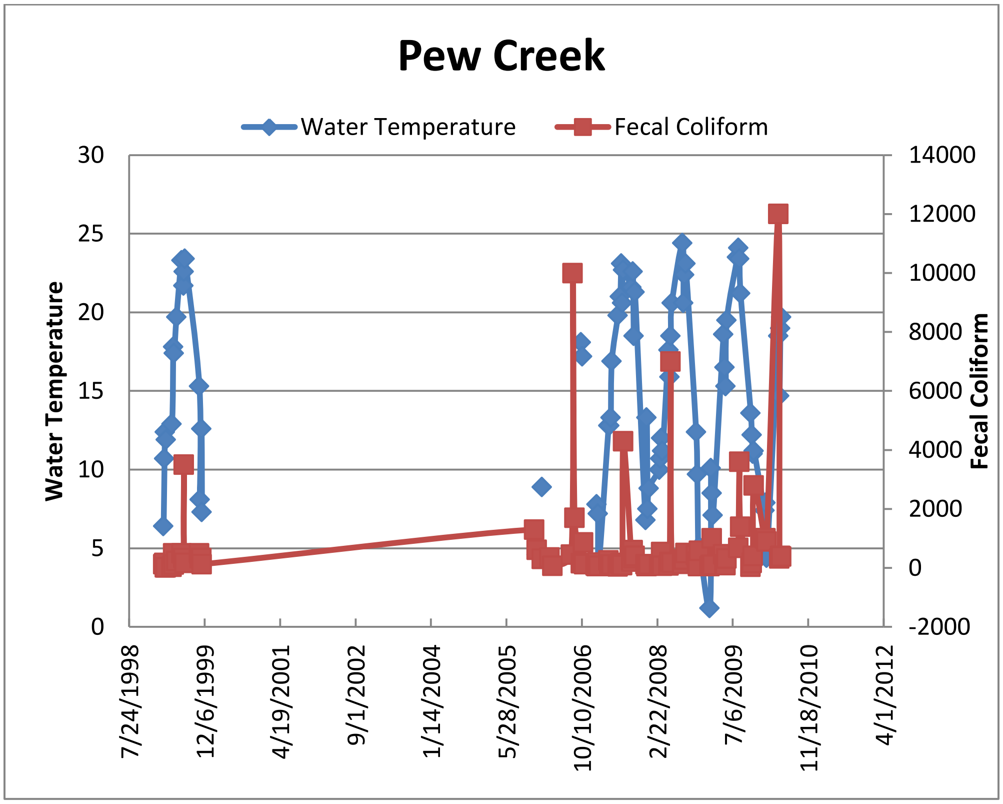

Figure 51. The relationship of water temperature and fecal coliform in Pew Creek (Yellow River Basin station Y2).

Another trend that was observed between these two river basins was the timing of when there were fecal coliform increases. The high fecal coliform readings sometimes corresponded at the same time between basins and at other times they do not. Figure 52 shows the relationship between fecal coliform in the Yellow River basin at Station Y2 and the Alcovy River basin at Station A2. Note that some of the peaks correspond to each other from both basins where other peaks are observed only in one of the basins.

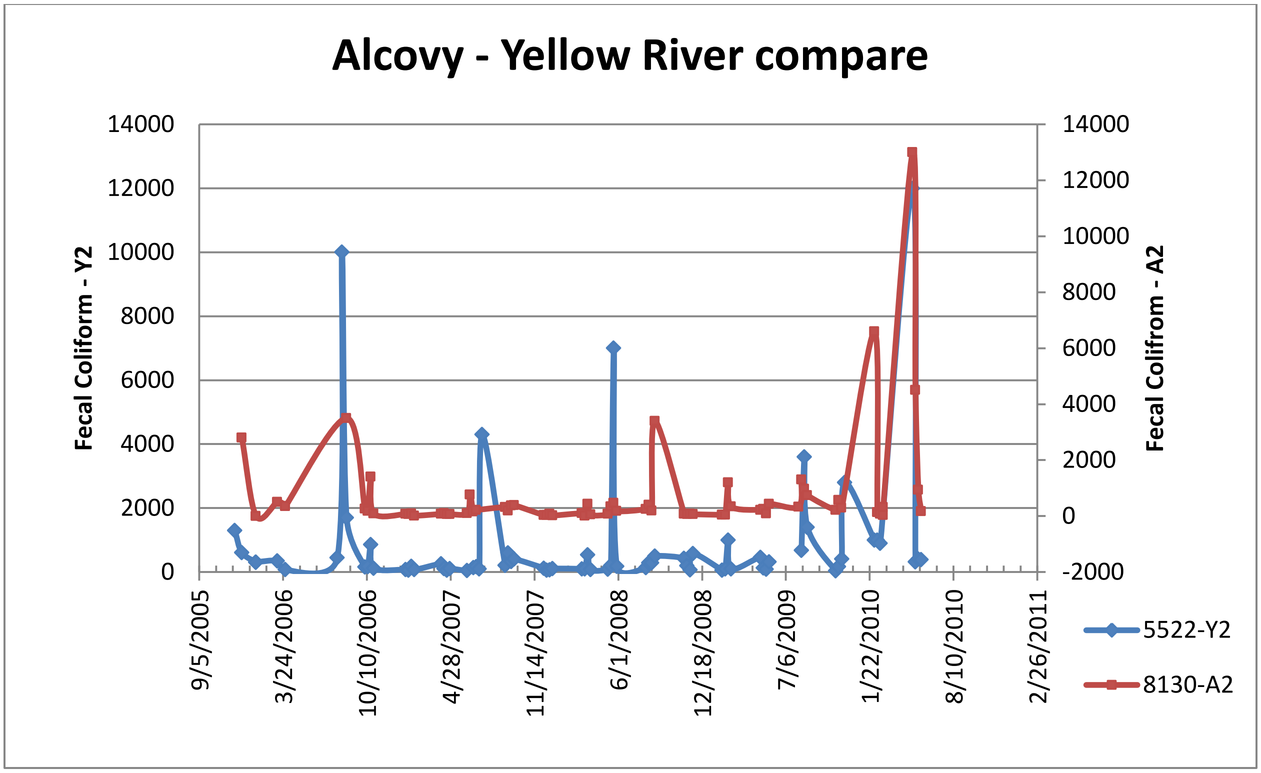

Figure 52. Correlation of fecal coliform in the Yellow River basin at station Y2 and the Alcovy River basin station A2 from 2005 to 2010.

A similar trend was also observed for the time period 1996 to 2000 between the Yellow River basin station Y4 and the Alcovy River basin station A4. Figure 53 shows those trends. Figure 54 shows the relationship between fecal coliform for 7 localities within this study, the 4 Yellow River basin localities and 3 of the Alcovy River basin localities for the year 1999.

Annual mean values for each water quality parameter and hydrologic parameter measured for each locality that had data from multiple years were determined. The localities that have multiple years of data are Yellow River station 2, 1999 to 2010; Yellow River station 3, 1969 to 1999; Yellow River station 4, 1996 to 2007; Alcovy River station 2, 2005 to 2010; Alcovy River station 4, 1996 to 2000. Since Yellow River station 1, Alcovy River stations 1 and

3 the data was from only one year the statistics are shown in Tables A1, A5, and A7 in Appendix A.

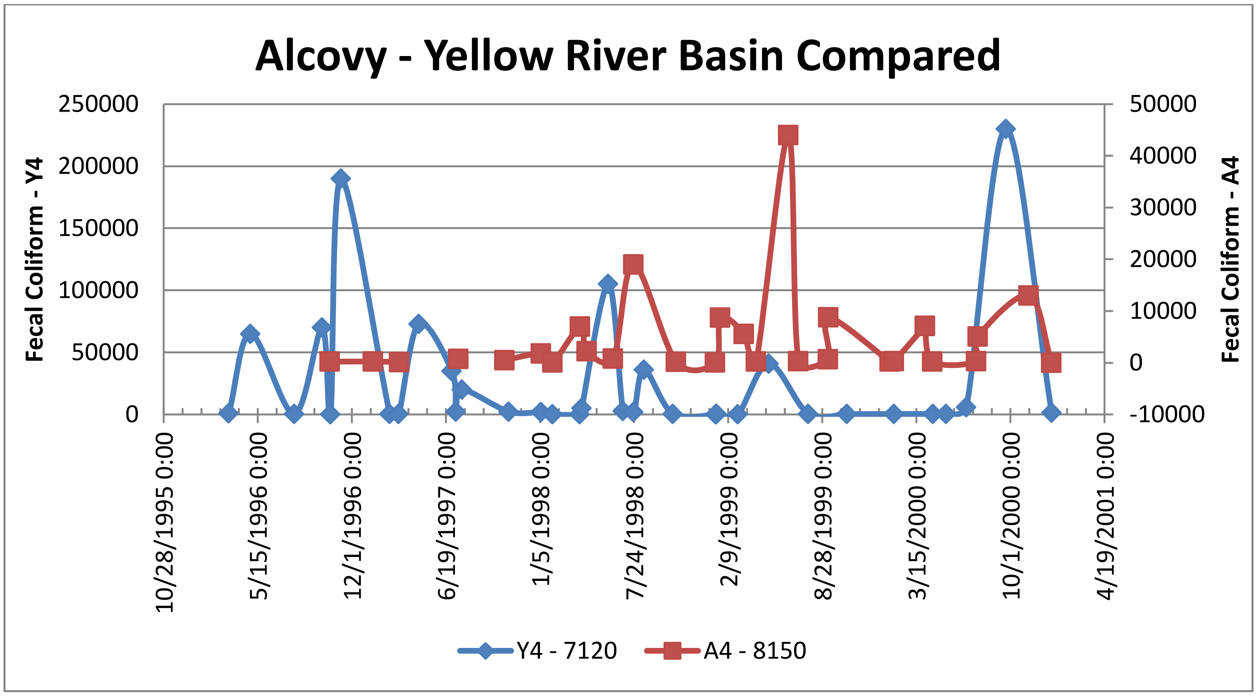

Figure 53. Correlation of fecal coliform in the Yellow River basin at station Y4 and the Alcovy River basin station A4 from 1996 to 2000.

The summary of the least-squared linear regression lines equations and the coefficients of determination (R^2) are shown in Table 9. The graphs of the annual mean fecal coliform and total rainfall for the rain interval (7, 14, 21, or 28 days) that had the highest value of R^2 is shown in Figures 55 to 59.

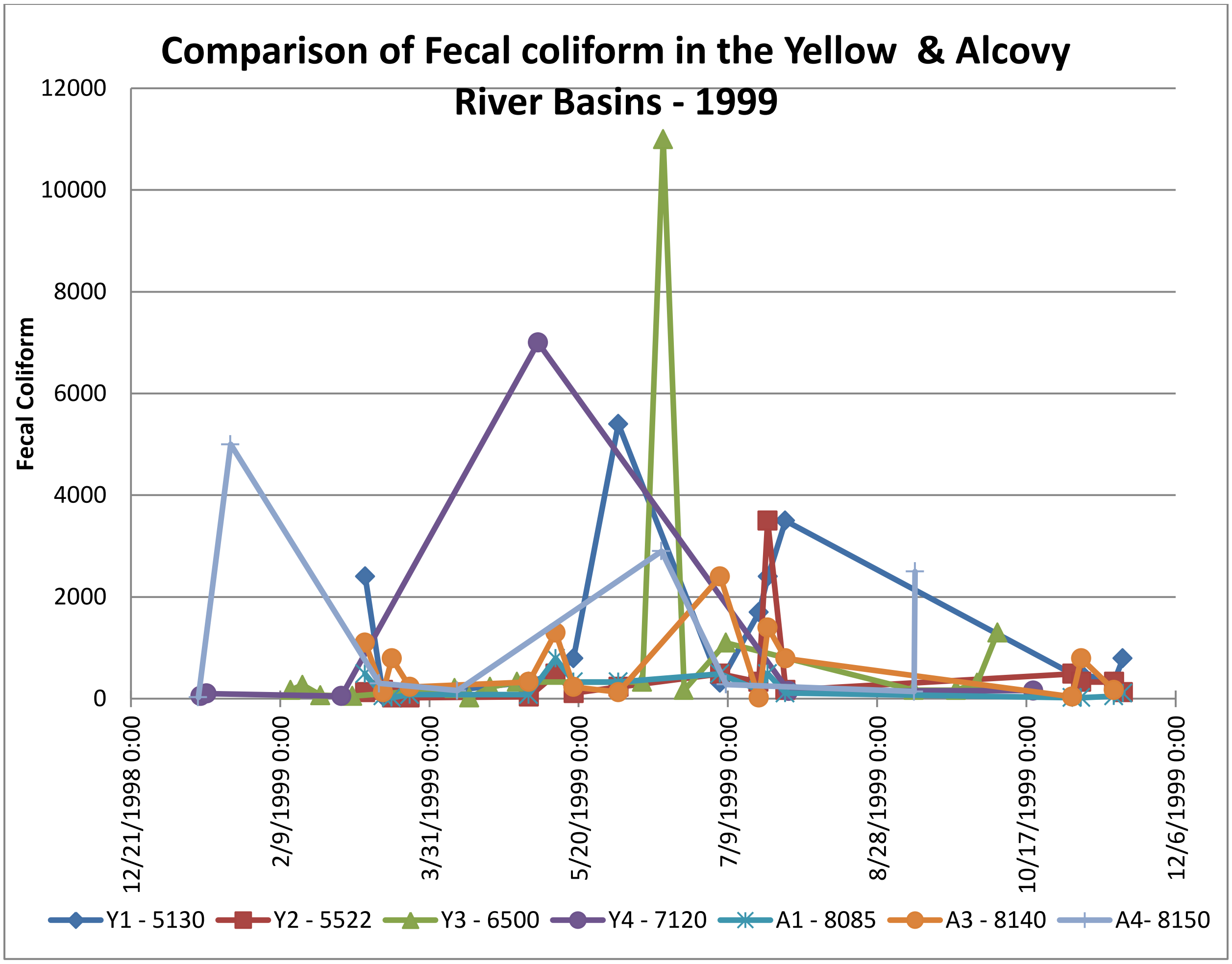

Figure 54. Comparison of Fecal coliform trends for 1999 in the Yellow and Alcovy River Basins.

The annual mean values for fecal coliform, water temperature, pH taken in the field, gage height, dissolved oxygen and the total rainfall for the 7-days prior to the water quality reading are shown in Figures 60 through 70. The trends of these graphs tell a great amount of information about the changes that have taken place through time in the Yellow and Alcovy River Basins in Gwinnett County, Georgia.

Table 9. Annual Mean total rainfall to fecal coliform least-squared linear regression results for 7 days prior to reading, 14 days prior to reading, 21 days prior to reading, and 28 days prior to reading (Figures B1 to B20 in Appendix B).

Locality	7-day			14-day			21-day			28-day			N=
	Slope	y-intercept	R^2	Slope	y-intercept	R^2	Slope	y-intercept	R^2	Slope	y-intercept	R^2	
Y2	0.0048	19.879	0.432	0.0127	38.869	0.500	0.019	53.311	0.679	0.0226	72.321	0.591	7
Y3	0.001	20.335	0.256	0.0012	47.935	0.171	0.0024	70.35	0.363	0.0024	94.818	0.274	27
Y4	0.0003	21.541	0.051	0.001	39.315	0.180	0.0007	68.364	0.094	0.0002	95.557	0.007	6
A2	0.0064	19.342	0.483	0.0144	35.866	0.710	0.0204	51.409	0.879	0.0259	68.902	0.858	6
A4	0.02	2.8895	0.636	0.027	21.308	0.451	0.0079	67.451	0.100	0.014	86.161	0.080	5

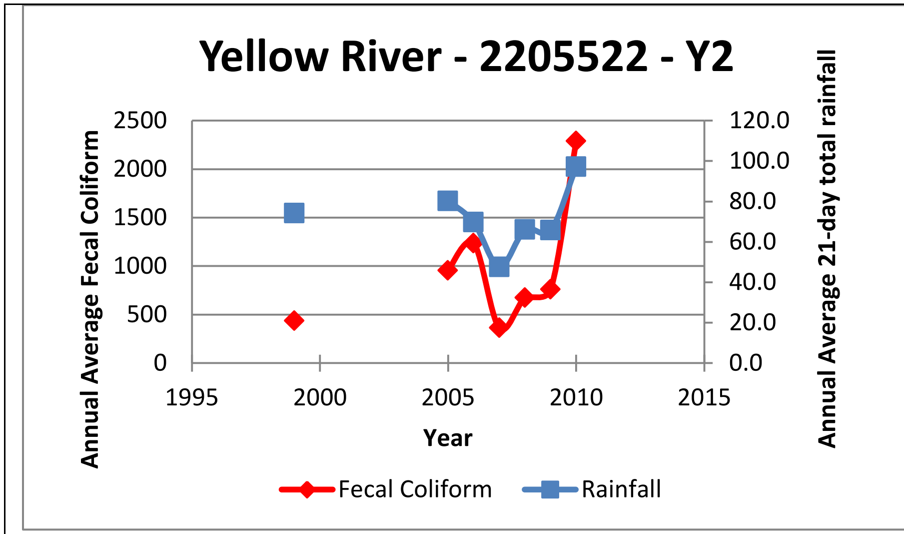

Figure 55. Mean Annual Fecal Coliform trend compared with Mean Annual 21 day total rainfall for the Yellow River basin station 2.

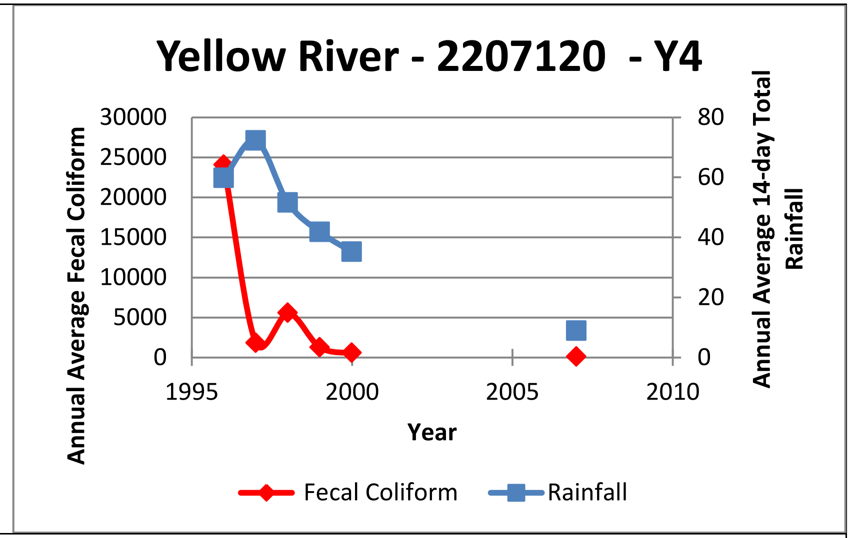

Figure 56. Mean Annual Fecal Coliform trend compared with Mean Annual 21 day total rainfall for the Yellow River basin station 4.

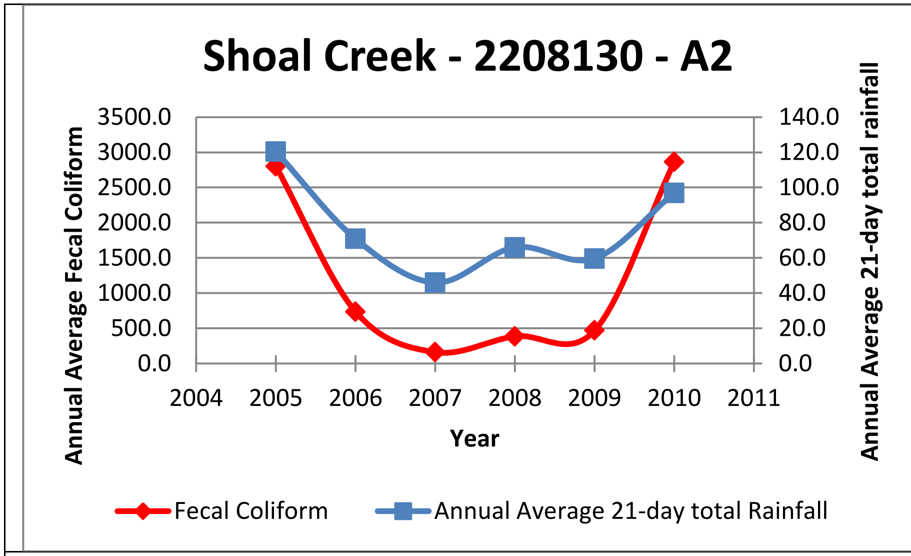

Figure 57. Mean Annual Fecal Coliform trend compared with Mean Annual 21 day total rainfall for the Alcovy River basin station 2.

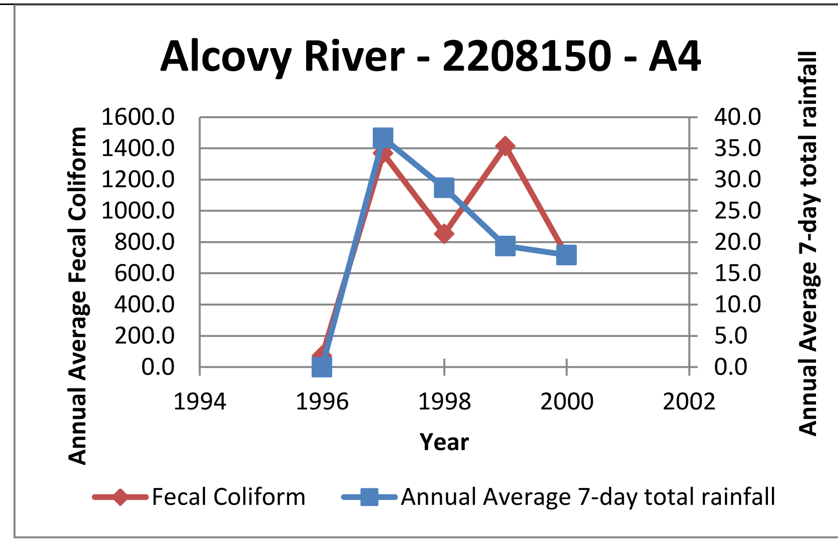

Figure 58. Mean Annual Fecal Coliform trend compared with Mean Annual 7 day total rainfall for the Alcovy River basin station 4.

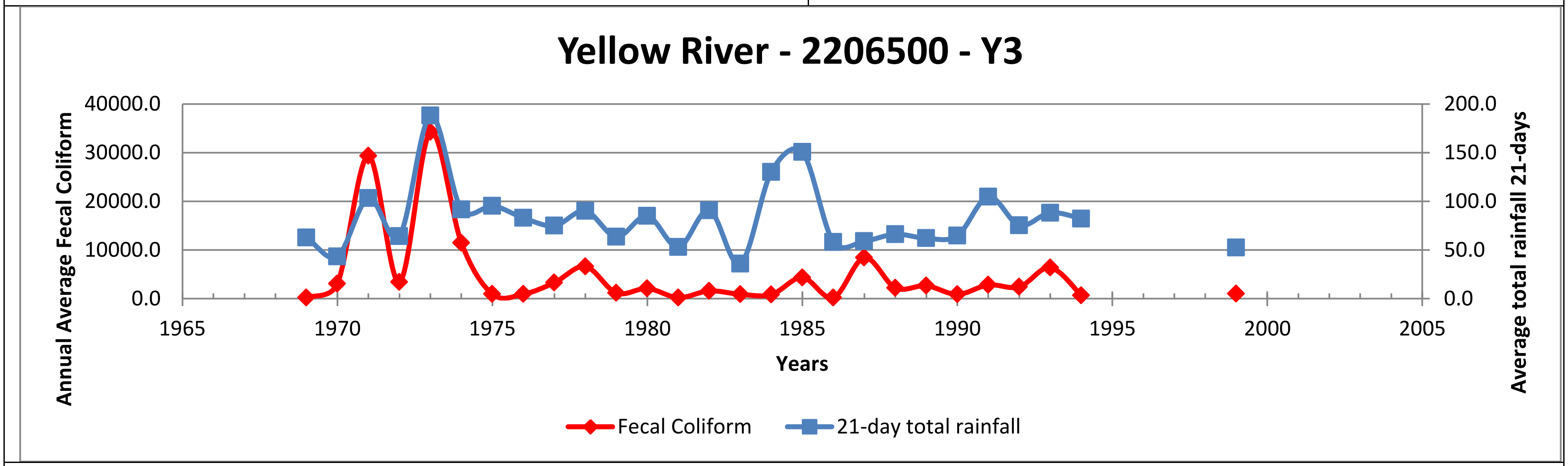

Figure 59. Mean Annual Fecal Coliform trend compared with Mean Annual 21 day total rainfall for the Yellow River basin station 3.

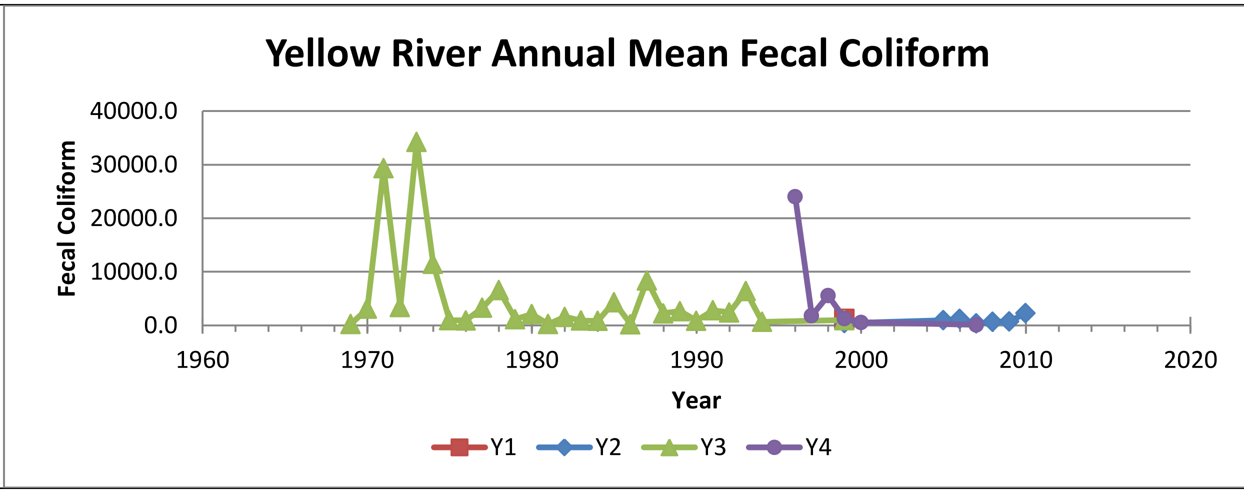

Figure 60. Yellow River Annual Mean fecal coliform for the 4 stations studied.

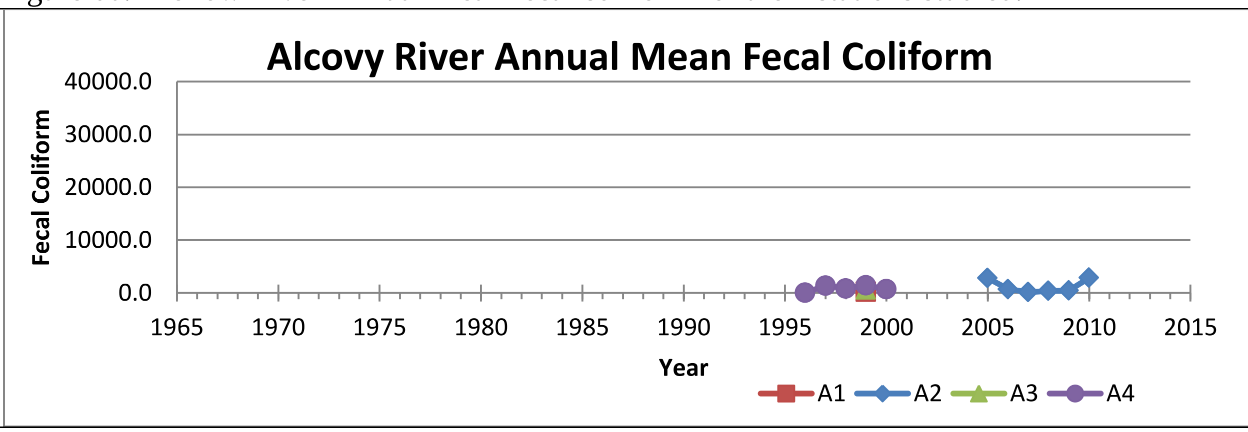

Figure 61. Alcovy River Annual Mean fecal coliform for the 4 stations studied.

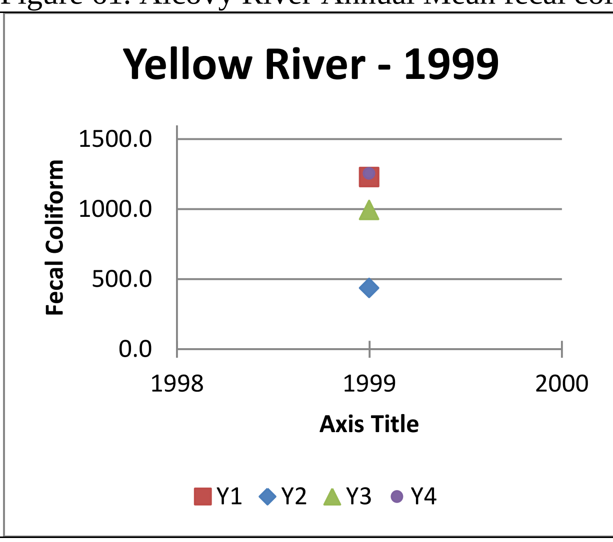

Figure 62. Mean fecal coliform values for the Yellow River basin in 1999.

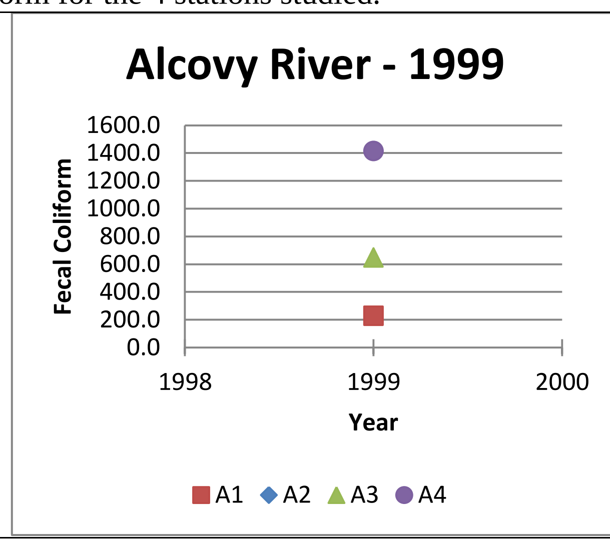

Figure 63. Mean fecal coliform values for the Alcovy River basin in 1999.

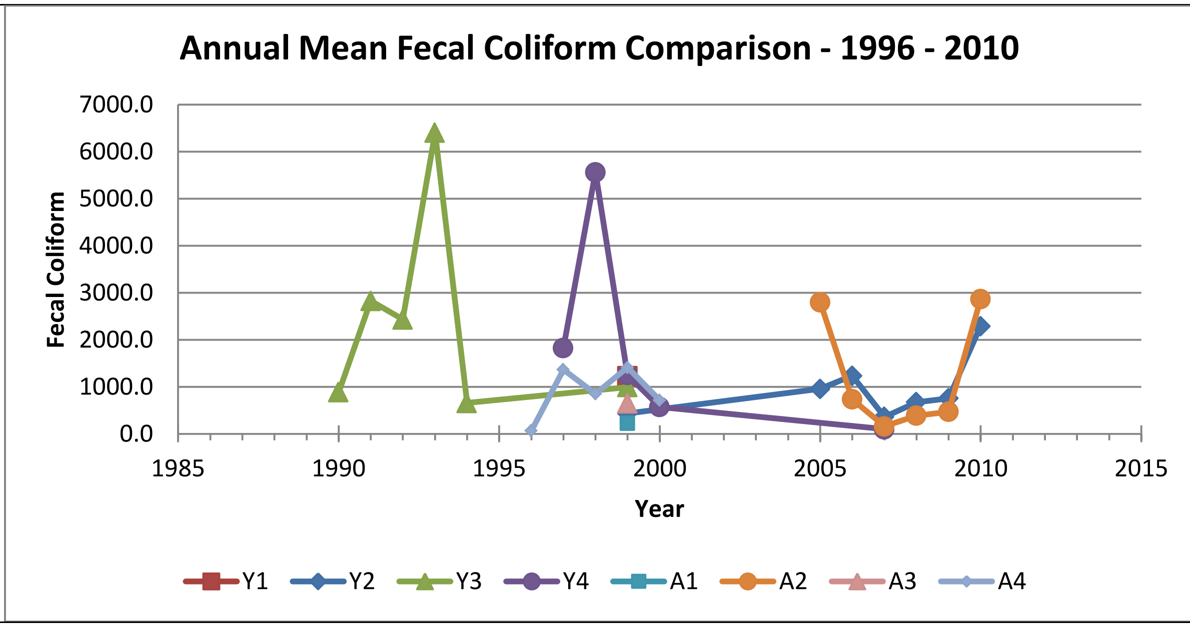

Figure 64. Annual mean fecal coliform trends from 1996 to 2010 in the Yellow and Alcovy River Basins, Gwinnett County, Georgia.

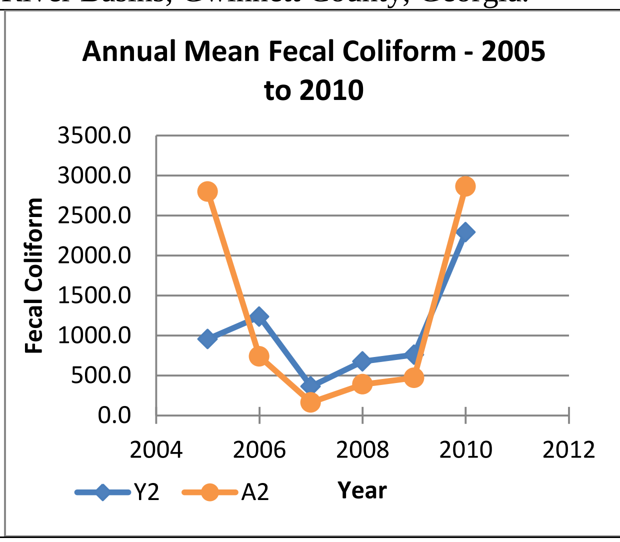

Figure 65. Annual mean fecal coliform for 2005 to 2010 for the Yellow River basin station 2 and the Alcovy River basin station 2.

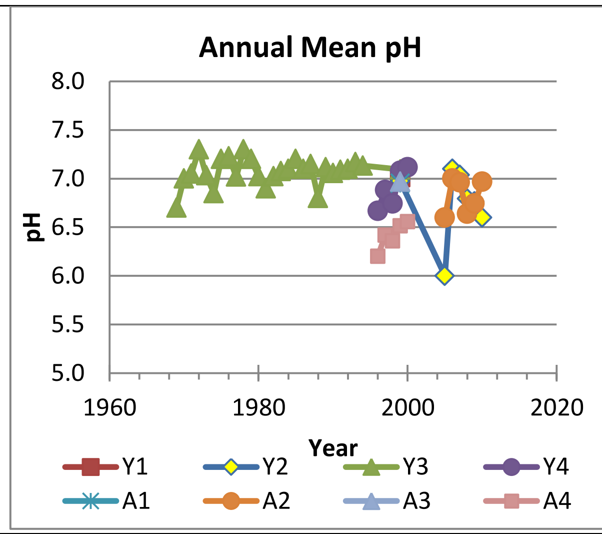

Figure 66. Annual mean pH for the Yellow and Alcovy River basins in Gwinnett County, GA.

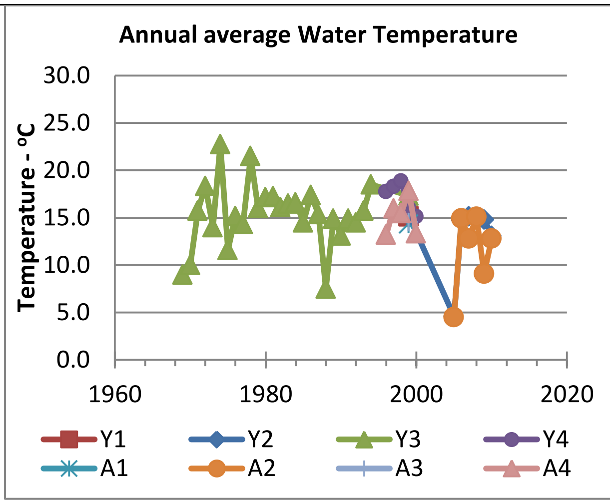

Figure 67. Annual mean water temperature for the Yellow and Alcovy River basins in Gwinnett County, GA.

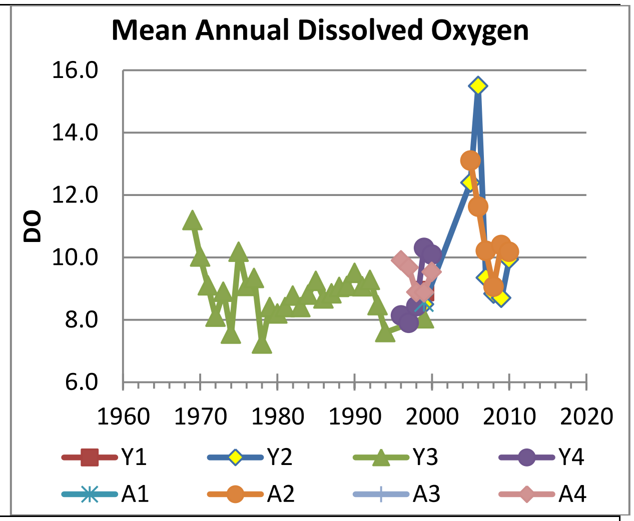

Figure 68. Annual mean dissolved oxygen for the Yellow and Alcovy River basins in Gwinnett County, GA.

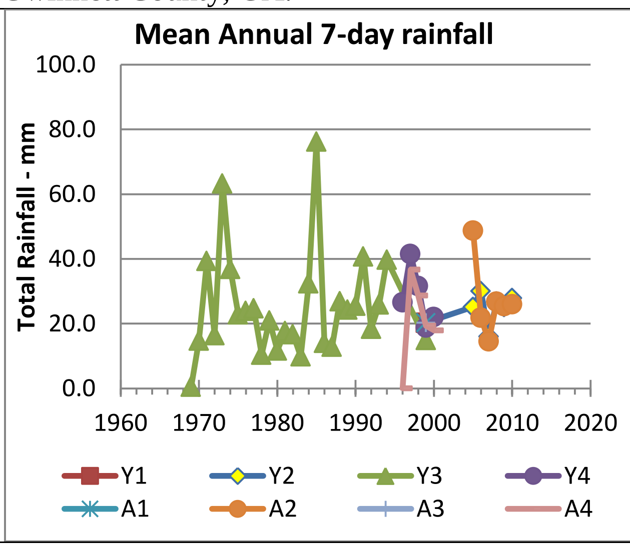

Figure 69. Annual mean 7-day total rainfall for the Yellow and Alcovy River basins in Gwinnett County, GA.

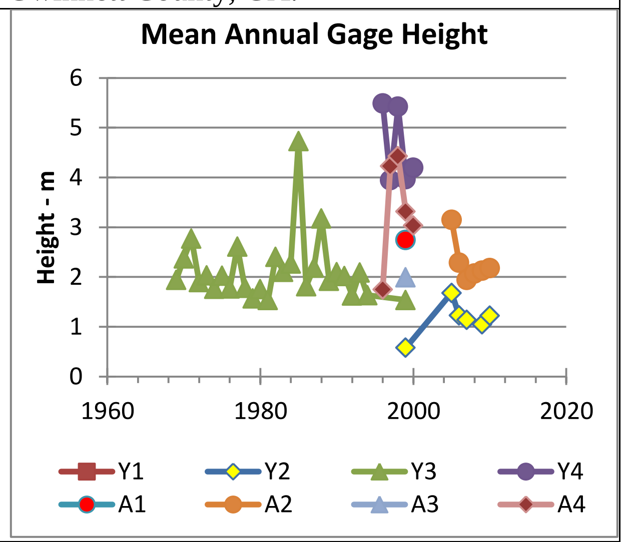

Figure 70. Annual mean Gage Height for the Yellow and Alcovy River basins in Gwinnett County, GA.

5. DISCUSSION

5.1 Number of Septic Systems in the County

Figure 10 shows that the infrastructure for the sewers parallels the major roads and highways within the county. Highways on this map are clearly observed as white lines on the map especially in the areas with the sewer system. The areas with high density septic systems are in areas with secondary and tertiary roads that are less visible on Figure 10. As observed in Figure 11, towns and municipalities in the county have sewer systems except for Norcross and Buford cities. These two towns are the older towns within the county and their development was well before the construction of the water reclamation facilities. Dacula, which recently has undergone residential expansion, has high septic systems because it is more rural and the county did not install sewer lines to this portion of the county, as what was installed for Snellville, Grayson, and Loganville areas. Figure 11 also clearly shows that the high density septic systems are found in the unincorporated areas of the county away from the major highways within the county.

As pointed out earlier Georgia law in the Official Code of Georgia, (2007) mandates that properties that are within 200 feet of a sewer line are to be connected to the sewer line. As observed in Figure 12 these properties are scattered throughout the county with the largest areas in the eastern portion of the county along with the northern portion of the county. This is the more rural portion of the county and the properties are large so large areas could be removed from being affected by septic effluent, but the feasibility of this is less likely because it even though it reduces the total area on septic systems it actually increases the number of septic systems per square mile. It is intriguing that the region with the greatest number of water reclamation facilities has a high septic system density in close proximity of these facilities (see figure 9). It is surprising that there are not a significant number of properties in this area that should be on sewers because of their proximity to sewer lines (see Figure 12).

At present the overall county density of septic systems is 221 septic systems per square mile (85874 septic systems/387.3 sq. miles), but the density for the area that have septic systems is 487 septic systems per square mile (85874 septic systems/175.6 sq. miles). If the properties within 200 feet of a sewer line were placed on the sewer system the total area of the county serviced by sewers would increase from 55% to 77%, which would be a significant decrease in the area of septic systems (a change of 22%). The change in the number of septic systems would be a total of 29,395 septic systems placed on the sewer system. This would be a change from 68% of the county on sewers to 79% of the county or an increase of 11%. Even though this would reduce the amount of area with septic systems and the number of septic systems would decrease the overall density of septic systems in the county would still be extremely high at 145 septic systems per square mile (56179 septic systems/387.3 sq. miles). The area of the county with septic systems would be 79.9 sq. miles, thus the density with septic systems would increase to 625 septic systems per square mile (56179 septic systems/79.9 sq. miles). This increased density of septic systems would be the result of large properties with only a single septic system on them would be taken out of the total area with septic systems, thus the total density of the county would increase. I believe this number may be the more accurate density of septic systems in the county at the present time. As stated earlier the properties in the east and northeastern portion of the county are large properties thus reduce area serviced by septic systems, but these areas right now have low septic system densities than those east of Lilburn in the southern portion of the county thus the density within the area with septic systems increases.

For the two drainage basins studied, the Yellow River and Alcovy river basins, they encompass over 55% of the total area of the county. The Yellow River basin is 40.6% of the area of the county where the Alcovy River basin is 14.6% of the county (See Table 10 for further statistics for these basins). As shown, in this table, within the Yellow River basin 66.5% of the basin is serviced by the sewer system where 33.5% of the basin is on septic. The Alcovy River basin is just about reverse of this with only 39.3% of the basin being serviced by the sewer system and 60.7% has septic systems. For the entire county these two basins represent 22.5% of the county's septic systems, by area, and 32.7% of the county's sewer system, by area. As noted earlier the Yellow River basin has water reclamation facilities, as shown in Figure 71, where the Alcovy River basin has none.

Table 10. Septic and Sewer Area Measures for the Yellow and Alcovy River Basins in Gwinnett County, Georgia.

	$Miles^2$	Acres	Septic	Sewer	Basin's %Septic	Basin's %Sewer	Basin's % of County	Septic % County	Sewer % County
Area of Yellow river basin	177.3	113,473.2	38,038.4	75,434.8	33.5%	66.5%	40.6%	13.6%	27.0%
Area of Alcovy River basin	63.9	40,877.7	24,811.3	16,066.4	60.7%	39.3%	14.6%	8.9%	5.7%
Area of County	436.7	279,459.0							
Number of properties		Total # Properties	Septic	Sewer	Percent septic	Septic/sq. mile			
Yellow River basin		124,075	39,881	84,194	32%	225			
Alcovy River basin		24,119	7,588	16,531	31%	119			

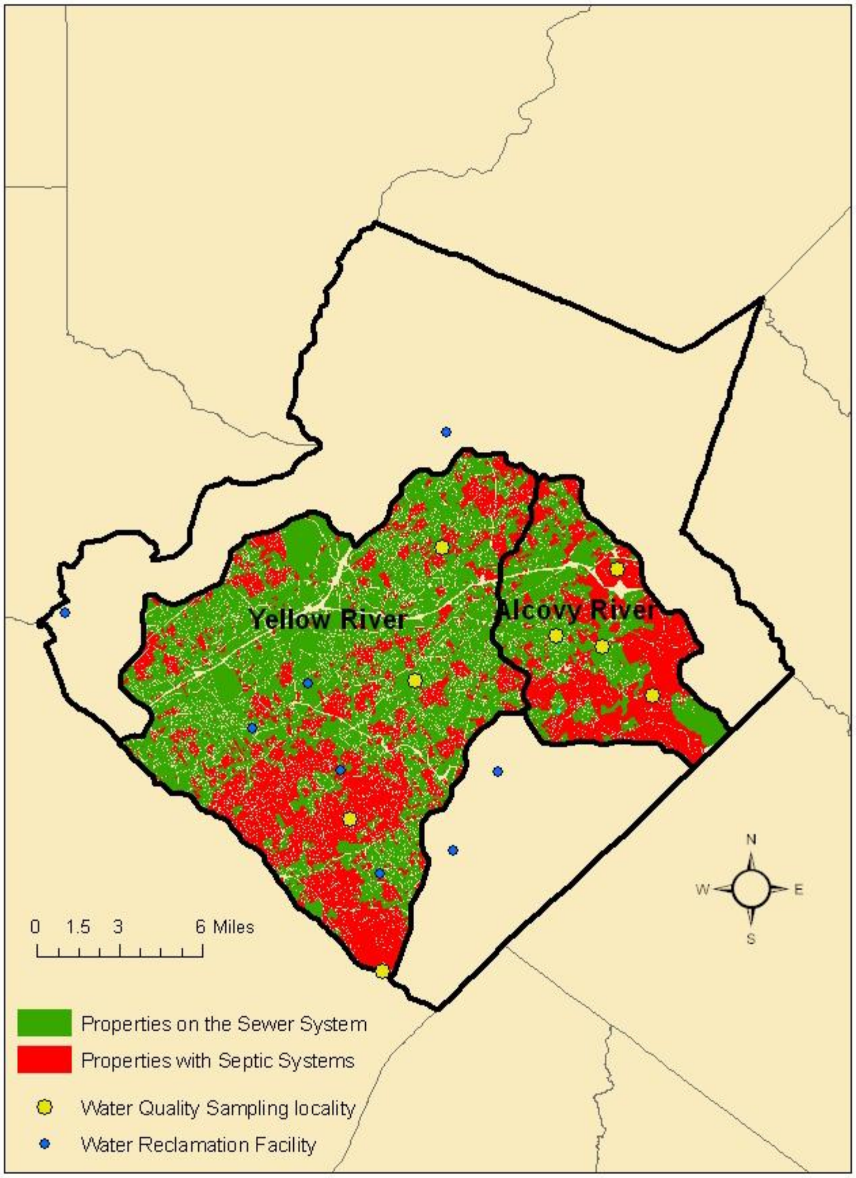

Figure 71. Map of Yellow River and Alcovy river basins showing the portion of the basin served by sewers and septic systems.

5.2 The Water Quality of the Yellow and Alcovy River Basins

The Yellow River basin is the largest drainage basin within the county and it has the largest number of water reclamation facilities in the county. So one of the questions that was addressed in this study was: Is the water quality of the Yellow River greatly affected by the WRF? Thus to get at an answer to this question the Alcovy River Basin was also studied because it has no WRF in the basin and it has comparable numbers of septic systems within that basin as what is found in the Yellow River basin. The percentage of the number of septic systems in the Alcovy River basin is 31% where 32% of the properties in the Yellow River basin are serviced by septic systems. The number of septic systems per square mile for the Yellow River basin is 224.9/ $mile^2$ where as the Alcovy River basin has 118.8/$mile^2$.

It was found that there were positive correlations between several metals (Pb. Zn, Cu, Cr, Mn, Mg, and Fe) in solution and fecal coliform within these two basins (Figures 13 through 19). Lead can have numerous sources from naturally occurring from the mineral galena to a host of human induced sources. An extensive list of sources of lead has been prepared by Elizabeth O'Brien (2010). The source of lead within the surface water in the Yellow and Alcovy river basins could be from runoff sources from roads and soil or from the leaching of lead in the soil from septic systems as the water is brought to the surface through flushing of the soil.

Zinc is used in the vulcanization of rubber and so it is often found in higher levels from runoff of highways. It is also found from industrial discharge, galvanized steel, car batteries, plastics, wood preservatives, antiseptics and some rodenticides (Oram, 2010). Copper has been found in surface waters from the wear of brake pads and the runoff from highways and roads (Hulskotte et al., 2006). It has also been found within sewage sludge that is then discharged into streams. It appears that the source of copper within the surface water is from highways and roads from automobiles and metal products that wear and are washed into streams. Chromium has similar pathways for its presence within surface water. It can be leached from topsoil and rocks as well as from leachate from landfills. Chromium is also a component in steel used for car bodies and parts (Agency for Toxic Substances, 2010).

Manganese is naturally occurring from rock and soil and can be released into the air as particulates from soil being blown into the air from vacant lots or from plowed fields (Williams-Johnson, 1999). It was also reported by Williams-Johnson (1999) that manganese can be from the combustion of unleaded gasoline that contain the organomanganese compound methylcyclopentadienyl manganese tricarbonyl (MMT) which is an additive for antiknock of car engines. Thus could be scrubbed out of the air by rain and then washed into streams.

Magnesium also is found naturally from rock and soil from the release from magnesium-rich minerals such as the amphibole and pyroxene minerals as well as the olivine minerals. These minerals are common within the rocks of the Atlanta area. Amphibolite is a very common metamorphic rock in the Atlanta area (McConnell and Abrams, 1984). Along with magnesium, iron is also found in these same metamorphic rocks. Magnesium is found in plastics and fertilizers so this element could be washed into surface waters from lawns. Magnesium is also found in steel used for car bodies thus could be washed into surface waters from roadways. (Water treatment solutions, 2010). Iron is a common element within rocks and soil. It is the red color within the soils of Georgia. Iron is the main component in steel thus could be washed into streams from roadways from the breakdown of steel as well as from the natural sources (Oram, 2010).

Besides the metals found in the surface water of Gwinnett County, Georgia, nitrogen compounds are found in significant concentration. These nitrogen compounds are ammonia, nitrates, and nitrites are shown in Figures 20 through 22. These nitrogen compounds have a host of sources from land-applied inorganic to organic fertilizers, manure, raw sewage, to septic systems (Sawyers, 2008). Thus these nitrogen compounds can be introduced into the surface water from flushing of septic systems to the surface or they may come from surface runoff from lawns that have been fertilized to properties with farm or domesticated animals, such as dogs.

Phosphorus within surface water has similar sources as the nitrogen compounds coming from fertilizers, manure, organic wastes, sewage and septic system effluent (USGS, 2010). It has been found that phosphorus tends to attached to soil particles and is moved by running water over the surface of the ground into streams. One of the major sources of phosphorus was from phosphate-rich [$(PO_4)^{-3}$] detergents and they were introduced into the surface water from waste treatment plants (water reclamation facilities, WRF) (USGS, 2010). The source of phosphorus could also come from septic system effluent as well through flushing of the effluent out of the soil.

Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Dissolved Oxygen (DO), Total Coliform, *Escherichia coli* (*E. coli*), and Fecal Coliform all are inter-related to either sewage effluent from WRF, septic systems or surface runoff of pet wastes. Figures 24 through 27 and Figures 43, 44, & 47 show the relationships of these parameters. The BOD is a measure of the quantity of oxygen used by microorganisms in the oxidation of organic matter. This occurs through the natural decomposition of plant matter within the water, but this process can be accelerated by human influences. Pet wastes, fertilizers, grass clippings, paper wastes can assist in the increase the oxygen demand in the water thus the amount of dissolved oxygen (DO) decreases as the BOD and COD increases (Withgott and Brennan, 2008, Ward and Trimble, 2003). Total Coliform, *E. coli*, and fecal coliform are measures of the amount of enterobacteria (bacteria that lives within the digestive system of mammals) within the water. This is generally measured as the number of colonies of bacteria per milliliter or liter of water. This is a direct measure of the amount of human influence there is on the area as well as the amount of runoff or flushing of the groundwater to the surface (Withgott and Brennan, 2008; Bitton and Gerba, 1984; Craun, 1979; Dawes and Goonetilleke, 2003; Francy et al., 2004; Gerba and Bitton, 1984; Wicklein, 2004).

Other water quality measures observed in Gwinnett County, Georgia include the amount of suspended solids, the turbidity of the water, and the specific conductance of the water (Figures 28 through 30 and Figures 45 & 49). Turbidity and suspended solids relate to the amount of particulate matter suspended in the water. These particles scatter the light causing the water to look cloudy. These suspended solids come from silt and clay from the soil as well as organic and inorganic matter, colored soluble organic compounds, as well as plankton and microorganisms such as fecal coliform or *E. coli* (Fetter, 1994). It is observed that with increased flow the water becomes more turbid due to the bottom of the channel becoming stirred up as well as suspended solids flow into the stream from construction sites and less vegetated land surfaces. The specific conductance of water is the measure of the amount of salts dissolved in the water. The dissolved material allows an electrical current to pass through the water where distilled water has a very low to no conductance. It is found that an increase in specific conductance can indicate less water within a stream where a decrease in specific conductance indicates more water within the stream. With more water there is a dilution of the dissolved material thus less electrical current will pass through the water. During low water periods the water becomes more concentrated in dissolved material thus will conduct more electrical current through the water (Our Lake, 2010).

The hydrogen ion concentration and pH are related to each other. The hydrogen ion concentration to the negative log is pH, thus when the hydrogen ion concentration goes up the pH of the water goes down since it is the negative or opposite. Figures 31, 33 and 48 show the relationship of these measures within the Yellow and Alcovy river basins of Gwinnett County. A decrease in the pH or an increase in the hydrogen ion concentration is observed with an increase in the amount of rainfall.

Water temperature is a factor of weather conditions, the amount of shade as well as the discharge of different temperature water from human sources. Warmer water is often discharged into streams from power generation plants and other urban sources. Different temperature water can be discharged into stream from groundwater sources. In this study it was observed that warmer water temperatures were found when there were higher fecal coliform readings. This might be caused by discharge of effluent from WRF that is high in fecal coliform and warmer water due to the biological activity occurring within the water. This explanation does not explain the observation shown in Figure 51 along Pew Creek which is upstream from any WRF. Another explanation for the higher water temperature is from discharge of warmer water from septic effluent that is high is fecal coliform. A third explanation for warmer water temperatures during times of higher fecal coliform readings is that with the addition of fecal coliform from runoff or flushing from septic systems the fecal coliform warms the water due to the increased biological activity that it stimulates within the stream ecosystem. It is apparent from the scatter plot of water temperature and fecal coliform (see Figure 32) that there is a positive correlation between these two water quality parameters. It is observed in Figure 72 for the Yellow River basin Station 3 for the year 1999 that during the summer month that readings were taken there is a positive correlation of water temperature, fecal coliform and the amount of total rainfall for the 7-day period prior to the water quality measurement. Because the fecal coliform reading is very high for June 17, 1999 the rest of the year readings are being stunted.

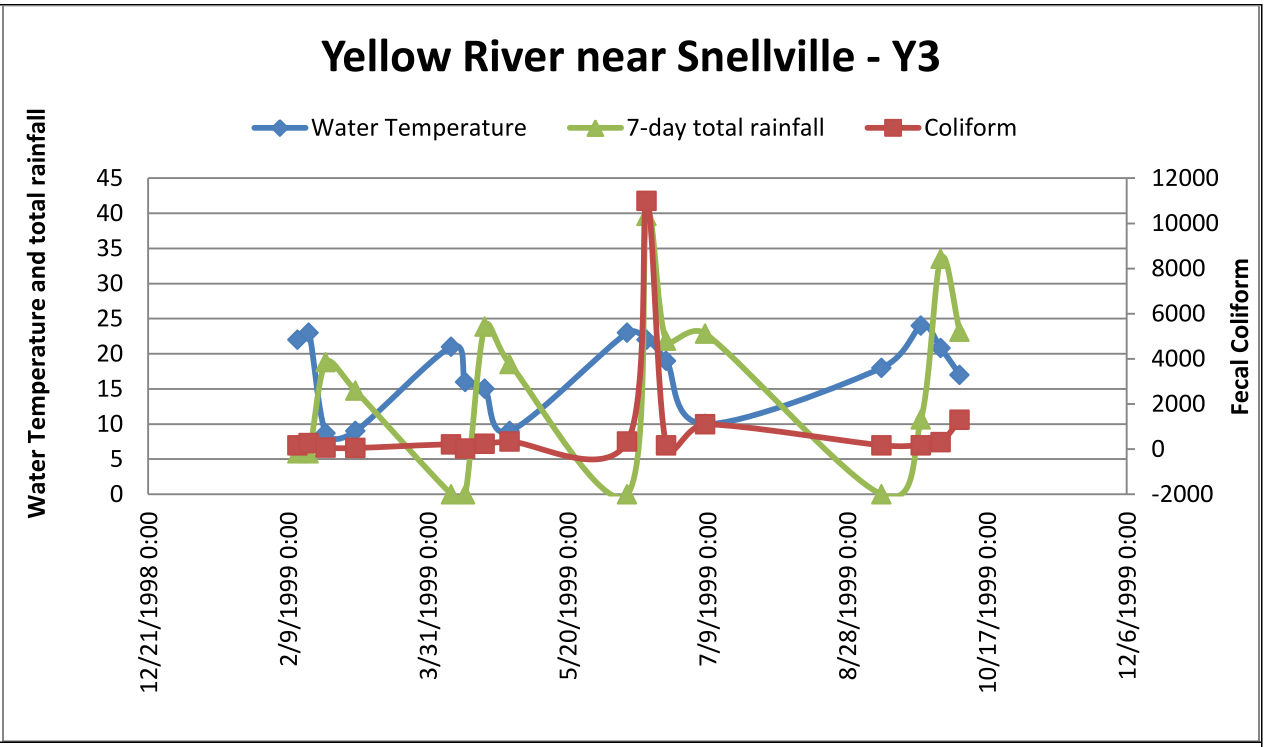

Figure 72. Relationship of fecal coliform, water temperature and the total rainfall 7 days prior to the water quality reading for the Yellow River station 3 near Snellville, Georgia for 1999.

By removing the June 17, 1999 reading from the graph, the trends of water temperature, fecal coliform, and total rainfall for the 7-day period prior to the water quality reading are much more observable (See Figures 73 and 74). Figure 73 is the graph of these parameters in 1999 prior to June 17 and Figure 74 is the graph after June 17 for the rest of the year 1999.

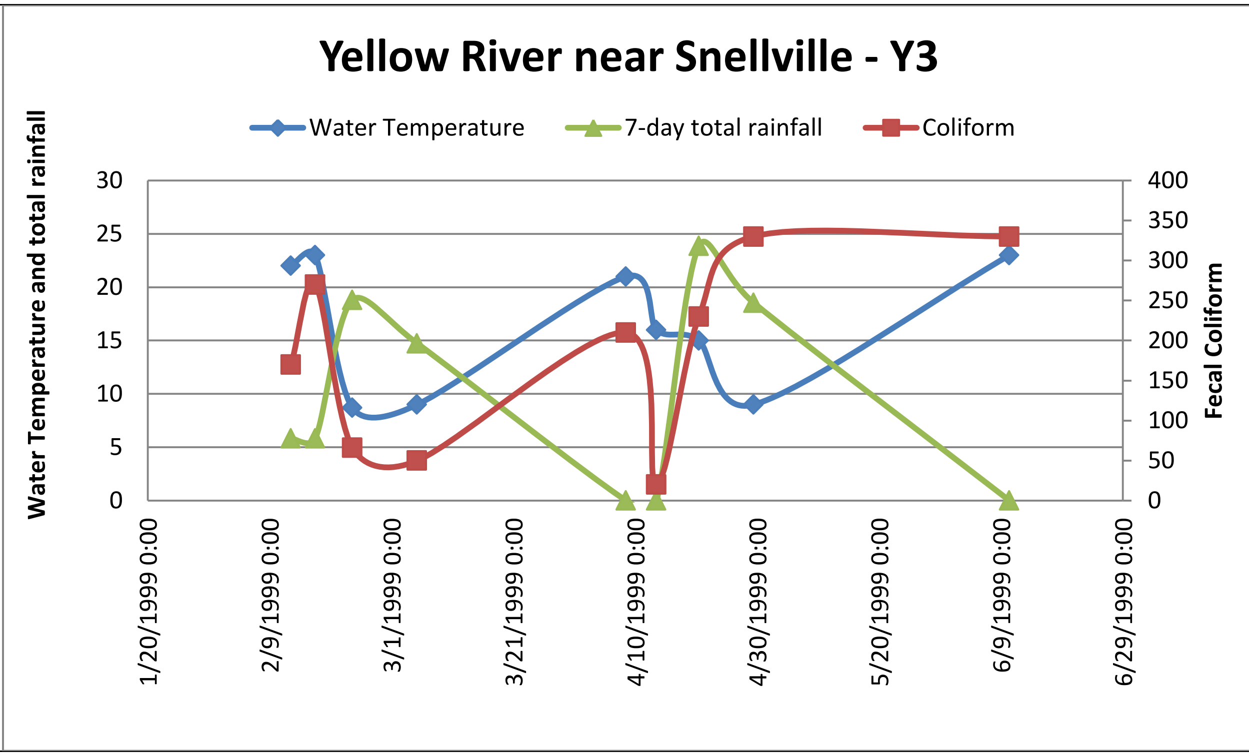

Figure 73. Relationship of fecal coliform, water temperature and the total rainfall 7 days prior to the water quality reading for the Yellow River station 3 near Snellville, Georgia for prior to June 17, 1999.

There are two trends observed within this data between fecal coliform, water temperature, and total rainfall 7-days prior to the reading. One trend is it appears that during the winter months that there is a correlation between water temperature and the amount of fecal coliform within the water as observed in Figure 73. As the air temperatures increase in the spring and summer the relationship changes to a positive correlation of the amount of fecal coliform and the amount of rainfall as observed in both Figures 73 and 74. This trend appears to continue into the fall as the air temperatures decrease that affect the water temperature that decreases with the cooler air temperatures.

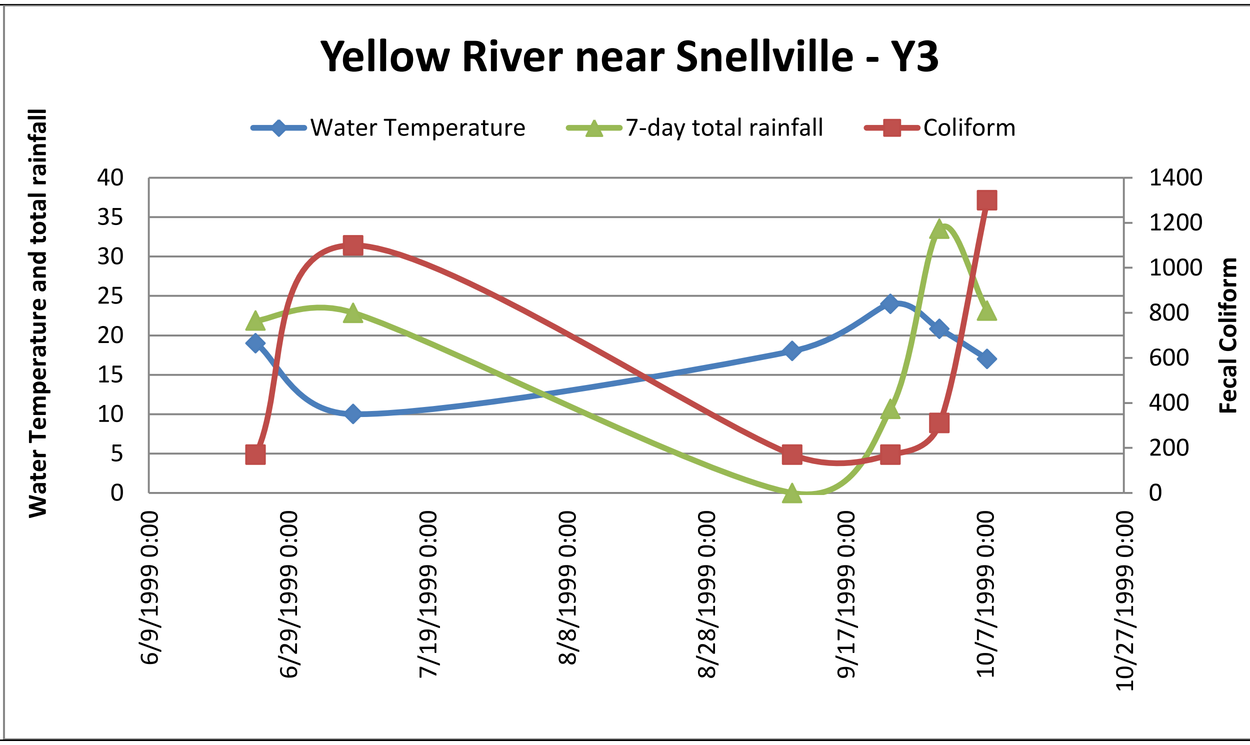

Figure 74. Relationship of fecal coliform, water temperature and the total rainfall 7 days prior to the water quality reading for the Yellow River station 3 near Snellville, Georgia for after June 17, 1999.

As the previous discussion introduced the relationship between the amount of rainfall and the increase or decrease in fecal coliform within the surface water, it is shown that there is a positive correlation between the amount of fecal coliform and the amount of rainfall. Figures 34 through 36 and Figures 38 through 41 show these relationships. It is observed that the best correlation is the rainfall event within the 7-day interval prior to the fecal coliform reading, but there are some strong positive correlations at the 14-day and 21-day total rainfall intervals for some of the collecting localities in this study. A related positive correlation to the amount of rainfall is the gage height of the stream that shows a positive correlation to the amount of fecal coliform within the water. The gage height is the measure of the amount of water within the steam channel which is related to the amount of runoff flowing into the stream (Figure 42). A second measure of the amount of water within the stream is the instantaneous discharge of the stream. This measure also has a positive correlation with the amount of fecal coliform measured within the stream as observed in Figure 50.

Several rainfall measurements were looked at in this study to determine the factor that best represents the cause of poor water quality within the Yellow and Alcovy river basins. Some of the rainfall measures did not have any relationships and others showed from the correlation coefficients that there was a significant relationship. Figure 37 shows the relationship between fecal coliform and the number of days of rainfall in the week 4 weeks prior to the water quality measurement. The scatter plot shows that there is a negative correlation. Thus with fewer number of days of rainfall 4 weeks prior to the water quality reading there will be more fecal coliform measured. This is an interesting relationship, but it appears that it is not a meaningful relationship.

Since this study was looking at the water quality for surface waters and how they were affected by high density septic system the one water quality measure that positively could be from septic systems is the measure of coliform, total and fecal as well as the amount of *E. coli* within the water. It has been shown that there is a positive correlation between fecal coliform and the amount of rainfall.

With WRF that discharge into the streams a question that could be asked: Is the fecal coliform and other bacterial measures related to the discharge of the WRF or can the fecal coliform be coming from septic systems? It would be thought that if the fecal coliform was coming from the WRF that the amount of fecal coliform in the water in the Alcovy River basin would be far below the levels in the Yellow River basin because the Alcovy River basin has no WRF in the basin. Figures 52 and 53 show the relationships between the Yellow and Alcovy

River basins in respect to fecal coliform. It is observed that the levels of fecal coliform are less in the Alcovy River basin than what is observed in the Yellow River basin as expected, but there are some readings in both basins that are about equivalent in intensity which would indicate that the WRF might not have that great of effect on the fecal coliform levels in the streams. It is observed that the times that there are high fecal coliform in one basin the other basin is experiencing a similar high level of fecal coliform, most often these are time of higher total rainfall. There are times though that one basin is experiencing high fecal coliform and the other basin has low to very little fecal coliform within the surface water. Again these relationships were made between stations A2 and Y2 (2005 to 2010), and A4 and Y4 (1996 to 2000) which have similar time periods of water quality measurements. The only year that the majority (7 of the 8 stations) had water quality measurements was in 1999. Figure 54 shows the relationship between the amount of fecal coliform for the 7 stations. This graph shows that the largest peaks in fecal coliform are from the Yellow River basin where there are WRF, but there are a few high peaks from the Alcovy River basin. The first major peak on the graph in early 1999 is from the Alcovy River basin station A4. It is interesting that for some of the major peaks there are lower peaks observed in several of the other collecting localities on the same day. There is also the relationship that there are higher readings of fecal coliform in the downstream stations and the upstream stations have lower readings, thus indicating that the tributary channels are adding to the amount of fecal coliform being measured. It is also observed that the highest fecal coliform measurement was made in the summer and the major peaks are observed between March and August with far less fecal coliform measured during the cooler periods of the year, except for the peak that occurred in the Alcovy River basin at station 4 on January 23, 1999. As observed in Figure 75 for the month of May, 1999, the highest fecal coliform value was in the Alcovy River basin at station 3, where the next highest reading for that same day was also in the Alcovy River basin at station 1. For the three dates shown the Alcovy River basin has some of the highest fecal coliform values for these dates. Alcovy River Basin station 3 is a higher order stream than the two Yellow River basin stations shown so there is the factor of increased discharge for the Alcovy River basin station 3. Comparing equivalent stream stations, Y1 and A1, the Alcovy River station has higher values than the Yellow River station.

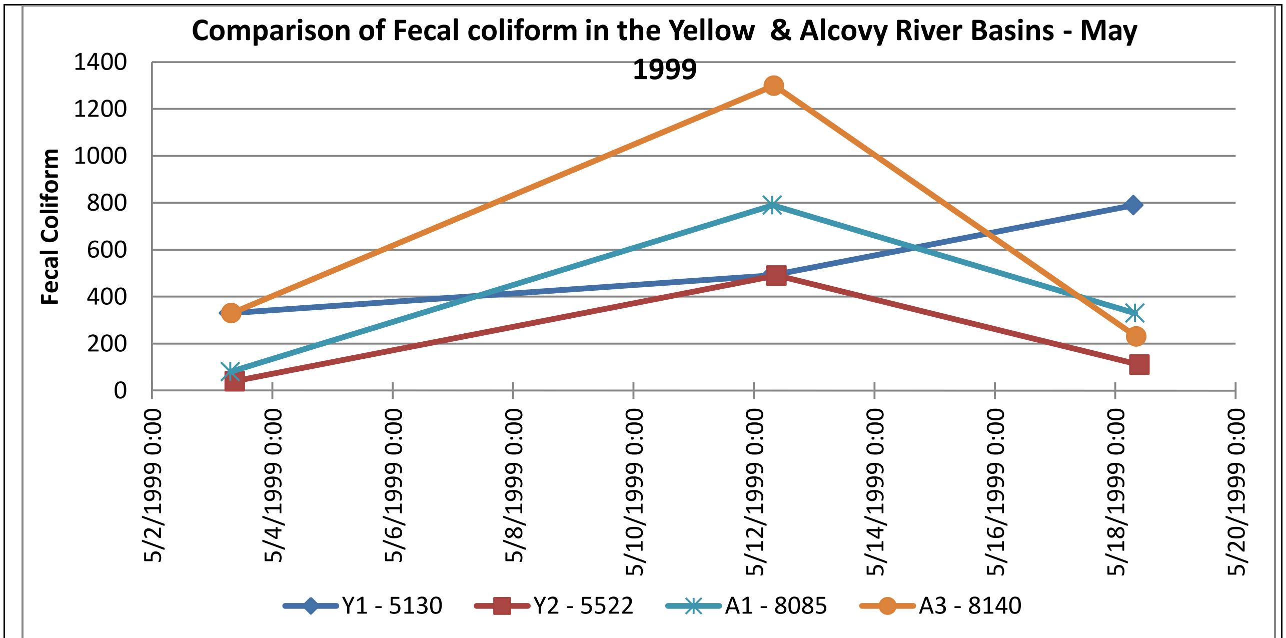

Figure 75. Fecal coliform relationships between the Alcovy and Yellow River basins for the month of May, 1999. Locality Y4 is not shown since it had a single high fecal coliform reading during the month that obscured the trends of the other localities.

5.3 Annual Mean Water Quality Measures for the Yellow and Alcovy River Basins.

The annual mean values for all of the water quality and rainfall measures were calculated to see if there were any trends through time that could be observed. Scatter plots of annual mean fecal coliform values and the annual mean for the 7, 14, 21, and 28 day total rainfall amounts were plotted and least-squared linear regression lines were determined. The regression line and

R^2 values are shown in Table 9. A trend that is observed in this table is that for the most part the y-intercept for each of these regression lines for the same rain interval is about the same, thus the y-intercept for the 7-day total rainfall interval is between 19.3 and 21.5. The slope of the line is steeper for the headwater stream segments and gentler for the downstream segments in the Yellow and Alcovy River basins. The coefficient of determination (R^2) is higher for the upstream locality and it decreases for the downstream localities. This may be a factor of dilution of the fecal coliform downstream compared to more concentrated in the upstream localities. This trend is observed for the most part in each of the total rainfall intervals (7, 14, 21, 28-day). Figures 55 through 59 show the annual mean fecal coliform to annual total rainfall value for the scatter plot that had the best R2 value for the linear regression line. It is observed that there is a positive correlation between the amount of rainfall and the amount of fecal coliform found in the stream for each of the 6 localities that had more than one year's worth of data. This data substantiates what was earlier observed in the locality data.

One of my initial premises was that fecal coliform should increase with the expansion of residential areas in Gwinnett County because the early development was predominantly septic system. Thus it should be observed that the average amount of fecal coliform in the streams should increase due to the increased load from septic systems being added to the streams. Figure 60 shows the mean fecal coliform for the localities studied in the Yellow River basin. As observed in this graph the mean fecal coliform values have decreased over time with just one spike in 1996. One explanation could be that over time newer developments were placed on the sewer system thus the fecal coliform measurements decreased through time. Another explanation for why the mean fecal coliform was higher in the 1970's is because there was more rainfall in the 1970's on average than what has been record since. Figure 76 shows the Mean

Total Rainfall for 21-days prior to the water quality reading for the high mean fecal coliform readings years in the 1970's were also very wet years, wetter than what has been recorded since that time. Figure 59 also shows this trend showing the relationship between fecal coliform and the 21-day total rainfall mean values.

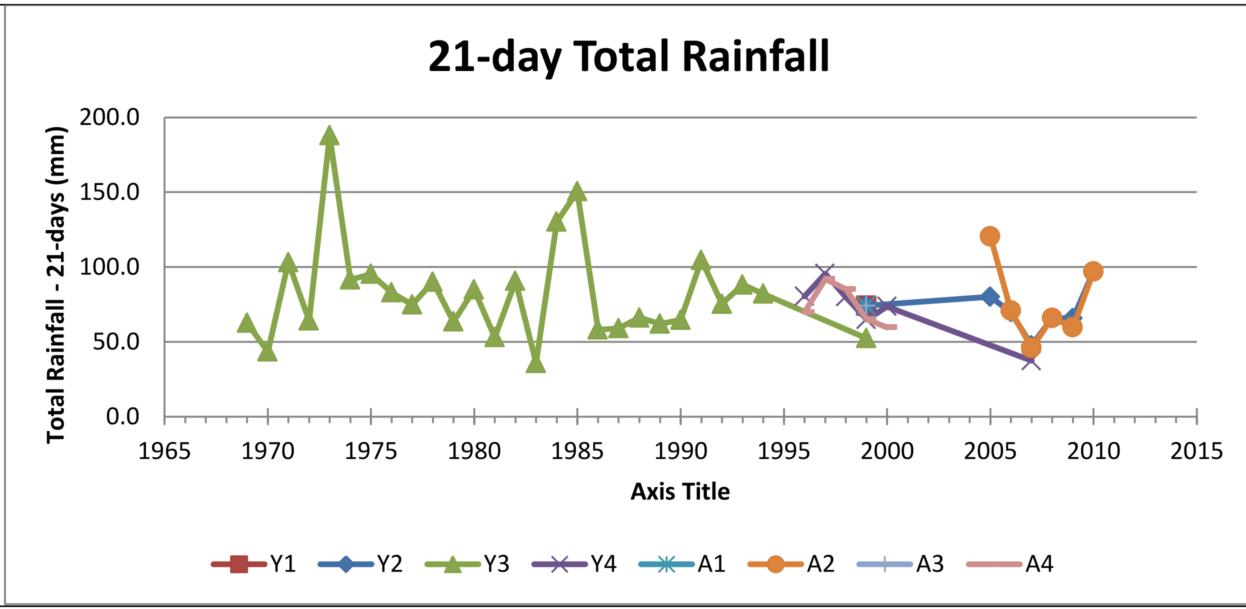

Figure 76. Mean Total Rainfall for the 21-day period prior to the water quality measurements for the Yellow and Alcovy River basins from 1969 to 2010.

Fecal coliform measurements for the Alcovy River basin don't extend back as far as what was measured in the Yellow River basin. Figure 61 shows the annual mean fecal coliform presented on the same scale as what was presented in Figure 60 for the Yellow River basin. This allows a comparison between these two basins to be made. The fecal coliform in the Alcovy River basin is much lower than what was recorded in the Yellow River basin in the 1970's. Figure 64 shows the mean fecal coliform values for both the Yellow and Alcovy River basins for the years 1990 to 2010. It is observed that the Yellow River basin had higher fecal coliform values than what was found in the Alcovy River basin during the 1990's. Since 2005 the mean fecal coliform values in the Alcovy River basin have been equivalent to those recorded in the Yellow River basin. Figure 65 shows this relationship between the Yellow River basin station 2 and the Alcovy River basin station 2 for the last 5 years. It is interesting that the years we had the drought (2007-2008) the average fecal coliform was lower than the wetter years prior to (2005-2006) and after the drought (2009-2010).

In 1999 seven of the eight localities had data for this year. Figures 62 and 63 show the mean fecal coliform readings for the Yellow River (Figure 62) and Alcovy River (Figure 63) basins for this year. For the Alcovy River basin (Figure 63) the highest mean annual fecal coliform value is observed from the most downstream location and subsequent lower fecal coliform values are found from the more upstream localities. In the Yellow River basin a similar trend is observed except for station Y1 which is the most upstream locality has a mean fecal coliform value equal to that of station Y4 the most downstream locality. This observation from the Yellow River station 1 might be explained due to this locality being more rural in 1999 and the runoff of fecal coliform from farmer fields or from septic systems since there are properties with septic systems in and around this collecting location. A more exact reason for this high mean fecal coliform measurement in 1999 will need further study to make a more clear determination.

Along with the annual mean fecal coliform the mean annual pH, water temperature, and dissolved oxygen were looked at. Figure 66 shows the trend of the mean annual pH for the Yellow and Alcovy River basins. The pH values for the entire time span shown are within the normal pH levels for a stream there has been a slight decrease in pH in the last ten years. This decrease in pH could be from an increase in pines contributing needles to the streams or on the land surface causing the runoff to become more acidic but the remote sensed images do not support this explanation. This decrease in pH could also be from acid deposition from rainwater and the decrease of pH from air pollution. Since the eastern portion of Gwinnett County is underlain by granite and granite-like (rock with similar mineral composition with granite) metamorphic rock the lower pH could be from the weathering of the bedrock that has been exposed due to the urban development exposing the rock to the surface. Figure 67 shows the trend of the mean annual water temperature for these streams through time. It appears that there has been a cooling to the mean annual temperature of the stream in the last 10 years. This may be a factor of cooling of the air temperatures or it may be a factor of an increase in groundwater input into streams. Ground water tends to be cooler in temperature than surface water because it tends to be the mean annual temperature of the surface temperatures. With this slight decrease in the mean water temperature there has been an increase in the mean annual dissolved oxygen content of the water as observed in Figure 68. This increase in dissolved oxygen could be produced by an increase in turbulence of the streams that often would be caused by an increase in the discharge of the stream, but the gage height, Figure 70, does not bear out that there has been an increase in discharge for the stream. Another explanation for the increase in the amount of dissolve oxygen in the water is due to the decrease in water temperature that allows more oxygen to dissolve in the water.

6. CONCLUSIONS

6.1 The density of septic systems within Gwinnett County and some possible solutions.

It has been shown in this study that 45% of Gwinnett County is serviced by septic systems in area, but that only constitutes 32% of the number of properties within the county. Even with what sounds to be a low percent of the county being on septic systems this is still a total of 85,574 septic systems within the county. The density of the county is well above what EPA defines as high density, 40 septic systems per square mile, at 221 septic systems per square mile for the entire county area with the density of 487 septic systems per square mile for the area with septic systems. If 40 septic systems per square mile is high density, 487/sq. mile, being 12 times what EPA stipulates, could be defined as extremely dense.

It has been shown that there could be 29,395 septic systems converted to being on the sewer system by simply following state law and connecting those properties that are within 200 feet of a sewer line, but the county does not make it affordable to homeowners to do this. The county will allow any homeowner to petition the county to be connected to the sewer system, but it is at the expense of the homeowner. The homeowner must find at least 5 other homes in the vicinity of their home to connect or the county will not undergo the construction as well as the cost per home ranges from $5,000 to $25,000 per home (MacGregor, 2005)

I would recommend what has already been proposed by the Metropolitan North Georgia Water Planning District in their 2003 report to create a long-term wastewater management plan for the district. From the 2003 report for this long-term plan they made this statement:

"The current system of regulating septic systems does not provide for their management. What little management of septic systems exists is through a variety of local ordinances and the overview of the DHR manual."

Thus it is recognized that there is not a management plan in place for septic systems within the North Georgia Water Planning District. So within the 2003 report they made some recommendations for the district on what actions needed to be pursued. One of their action plans was to improve siting, design, and construction by establishing additional septic system design requirements to supplement the DHR regulations. They proposed two recommendations (1) establish a minimum lot size requirement for placement of septic systems and (2) require the septic tank to be sized as if the home will have a garbage disposal, thus 50% larger than the number of toilets in the home. A second recommendation was to improve the maintenance requirement for septic systems. The single most effective way of extending the life of a septic system is to have it pumped every 3 to 5 years. If County Boards of Health would establish this requirement that homeowners have their septic tank pumped every 5 years and the local wastewater treatment plants accept the sludge that is pumped out would allow for better maintenance of septic systems within the District (North Georgia Water, 2003). This would add the burden of record keeping on the County Boards of Health to insure that homeowners have their septic tank pumped as well as add the burden on sludge pumpers/hauler to report when a homeowner does have their septic tank pumped, but it would improve the health of the areas with septic systems.

To better manage septic systems within the district the North Georgia Water District planning board recommended in their 2003 report that each county should create a septic system database so each county would have a better handle of where septic systems are located as well as to be able to track pumping records. They further recommended that septic system management should continue to be under the DHR but with EPD support so the quality of water within the county would be better monitored and related to the high-density septic system areas. They also recommended that septic system areas should be included in the local wastewater management plan so local governments could look at the feasibility of connecting aging septic systems to the sewer system as that infrastructure expands.

For those counties that find that private wastewater systems, septic systems, are needed because of the lack of sewer infrastructure in the more remote areas, they should enact policies that plan for the future expansion of the sewer system. One suggestion would be for developers to site in and install sewer lines into subdivisions that at present will be on septic systems but in the future will be able to be connected onto the sewer system. This would be proactive and allow homeowners to easily connect to the sewer system once it has expanded to their subdivision (EPA 2005, North Georgia Water, 2003). This will lower the cost in the future for the homeowner to connect to the sewer system and make it easier for the county to connect homes on septic systems to the sewers.

For areas that presently have septic systems but are within 200 feet of sewer lines the DHR rule that states that "a connection shall be made to a public or community sewage treatment system when such system is available within 200 feet of the property line or available in a public right-of-way abutting the property" (Official Code of Georgia, 2007) should be upheld. This would reduce the number of septic systems within the metropolitan Atlanta area and in particular in Gwinnett County. This should have a positive effect on water quality of surface streams and groundwater.

The last action that was suggested within the North Georgia Water Document (2003) was to improve or create a monitoring process of water quality for local streams. This would detect elevated contamination levels and for those contaminants that are related to septic systems action plans could be in place to mediate the problem. By using the septic system location database to determine areas with high-density septic systems and relating the contamination via GIS, counties could track problems and address how to better improve the water quality for impacted streams. The Health Departments could then go inspect septic systems to determine those that have failed and begin remediation. At present no monitoring program is in place by the counties and no databases of septic systems exist (North Georgia Water, 2003).

Along with the long-term wastewater management plan developed for the Metropolitan North Georgia Water Planning District, forecasts of septic tank wastewater flows were made by Jordan, Jones, and Goulding, Inc. (Technical Memo., 2003). They determined estimates of the range of future septic wastewater flow and addressed the possible impacts to water bodies, treatment facilities, and consumptive use quantities. They recognized that septic systems do add water to the groundwater system and in 2003 the drought conditions allowed this conclusion to be looked upon favorably. This report did recognize that the status quo use of septic systems within developing counties would by 2030 create problems for natural water systems, ground and surface water. One solution to this would be to restrict development to only subdivisions that will be placed on the county sewer system thus limit the growth of a county to those areas with sewers. Other proposed solutions would be to find funding sources for construction of new sewer infrastructure in new and old areas to reduce the need for septic systems in the new areas and allow older septic systems to be connected to the sewer system. The last suggestion was to develop policies that encouraged or required developers to connect to the community-based sewer system thus homes would never have to be connected in the future. If there were areas that just could not be connected at the present time developers could be encouraged or required to install dry sewers that eventually would be connected to the sewer lines once the infrastructure was extended to those subdivisions (Technical Memo, 2003). These recommendations would benefit the citizens of Gwinnett County if these were enacted.

6.2 The Implications of Water Quality within Gwinnett County.

This study has shown that the greatest factor involved in the amount of fecal coliform in the surface water of the Yellow and Alcovy River basins is the amount of rainfall. It was found that with an increase in total rainfall there was a direct correlation in the amount of fecal coliform in the surface water. This increase could be solely from surface runoff, but from my experience with owning a home with a septic system there are times that the ground has gotten saturated and it was noticeable that septic effluent was coming to the surface and was being washed into the small stream near my house.

The Yellow River basin with several WRF did have higher fecal coliform readings than was found in the Alcovy River basin that does not have any WRF. There were times, as observed in Figures 52 and 53, that the fecal coliform levels were higher in the Alcovy River basin than what were recorded in the Yellow River basin for the same exact day so the WRF is not the only source for high fecal coliform.

It was recognized that there are seasonal differences in the amount of fecal coliform in the surface water as observed in Figure 54. The warmer months of the year tend to have higher fecal coliform readings than during the cooler months, but there were high fecal coliform readings during the cooler months, as observed in Figure 54 for January 23, 1999. These peak readings shown in Figure 54 do correspond to high total rainfall for these basins. Figure 77 and 78 show these trends for the Yellow River basin stations 3 and 4 as well.

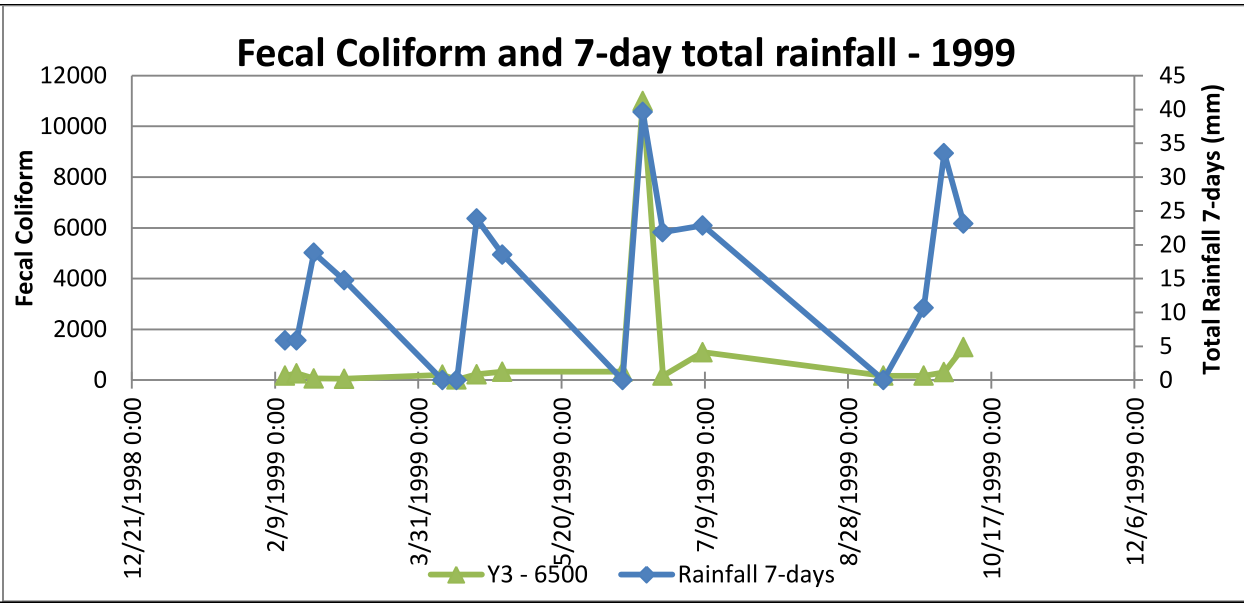

Figure 77. Relationship between fecal coliform and total 7-day rainfall for the Yellow River station 3.

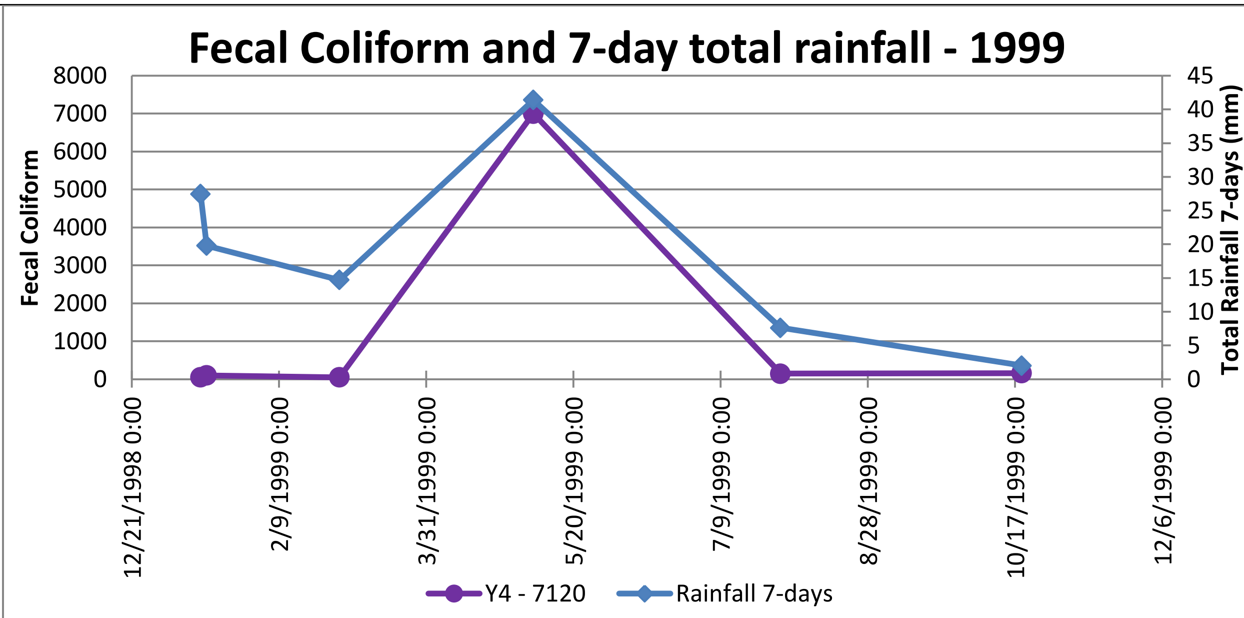

Figure 78. Relationship between fecal coliform and total 7-day rainfall for the Yellow River station 4.

For the nutrient water quality parameters such as ammonia, total nitrogen, nitrates, nitrites and phosphorus, the highest readings for these water quality parameters were recorded from the Alcovy River basin, as observed in Figures 20 through 23. These water quality measures come from the runoff of fertilizers from lawns and/or manure from agricultural lands typically as well as septic systems or WRF. Again the Alcovy River basin is the basin without any WRF that could be dumping treated sewage into the stream that would be high in these compounds. Thus it can be concluded that the high measures of total nitrogen, nitrates, nitrites and phosphorus must be coming from runoff of agricultural land, from lawns that have been treated with fertilizers or from flushing of the soil from septic systems. Since about 61% of the area of the Alcovy River basin is on septic systems I feel the best explanation for the elevated nitrogen and phosphorus compounds is from septic systems.

The metal ions of Lead, Zinc, Copper, Chromium, Manganese, Magnesium, and Iron measured in the surface water, as observed in Figures 13 through 19, all show a positive correlation with fecal coliform. For lead, zinc, copper, and chromium the highest measured values for these metals was found within the Alcovy River basin. These metals are indicative of a measure of the amount of runoff from urban/developed impermeable surfaces that accumulate and allow these metals to be transported into the surface water. The major sources for these metals being in the surface waters is from industrial process as well as automobile parts, as in copper coming from automobile brake pads. Thus these metals were transported to the streams from runoff of the roads and highways within these two basins.

With the use of unleaded gasoline the increase in the amount of manganese in the surface water could be explained from runoff from roads and highways. A manganese compound is an additive in gasoline to reduce the knocking of the engine, as lead was used in leaded gasoline. So the source of manganese could be runoff. Manganese could also have a natural source coming from minerals rich in manganese. The rocks of the Atlanta area have minerals rich in manganese. The soils in the Atlanta area have high manganese content as well. Thus the source manganese in the surface water may be from a human source or a natural source.

Iron and magnesium are elements found in the ferromagnesium minerals of amphibole, pyroxene and olivine. Amphibole and pyroxene are common minerals in the rock of the Atlanta area (McConnell and Abrams, 1984). With the high values of iron, magnesium, and manganese in the surface water, it can be concluded that these elements because they are abundant in the rocks and soils of the Atlanta area most likely are coming from a groundwater source. This might be associated with the flushing action of the rainwater during saturated times that also is bringing fecal coliform and other pathogens into the surface water.

It is evident that there is active biological activity in the surface waters of the Yellow and Alcovy River basins due to the increased Biochemical Oxygen demand (BOD), the decrease in dissolved oxygen (DO) as well as the increase in fecal coliform, total coliform and *E.coli* within the surface water. With the increase in BOD and the decrease of DO indicates that there is biological activity in the water causing the increase in BOD that causes the decrease in DO. The increase in fecal coliform, total coliform and *E. coli* indicate the potential for other biological organisms in the water such as water-borne diseases and viruses. These would pose a health risk for anyone who comes in contact with these waters.

This study has shown that there is a positive correlation between the amount of rainfall and the amount of fecal coliform in the water. Since fecal coliform is easily measured it is used as a surrogate for other water-borne pathogens that can cause health risks to humans. It was found that some of the other water quality parameters measured could be explained by flushing of these chemical out of septic system effluent into the surface waters of the Yellow and Alcovy

River basins. There was not a strong relationship that the fecal coliform main source in the waters of the Yellow River basin were from the WRF, but were either coming from surface water runoff of properties with pets, failing septic systems, or simply at aging septic systems have developed the inability to purify the water in the leach field (drain field) as studies have shown (Bitton and Gerba, 1984; Burns et al, 2005; Craun, 1979; Dawes and Goonetilleke, 2003; DeBorde et al., 1998; Fong et al., 2007; Francy et al., 2004; Nicosia et al., 2001: Robertson et al., 1991: Verstraeten, et al., 2004; Wicklein, 2004).

The best explanation for the high fecal coliform in the surface water of the Yellow and Alcovy River basins is from septic systems that are leaching or flushing their effluent to the surface. It could be just from the sheer quantity of septic system effluent in these extremely dense septic areas that these increased values are recorded. The best option for the county would be to acquire the funds needed to connect the older septic systems to the sewer system in the county. This would require a large out lay of funds as well as it would facilitate the need to construct new WRF in the county.

By taking the older septic systems if not all of the septic systems from the load of these streams it would potentially open the opportunity for the county to use the water from the Yellow River and possibly the Alcovy River as water supplies for the county. With the issue of the use of Lake Lanier as a water supply being an issue finding a viable source of water might be something that Gwinnett County would want to look into for the future.

7. FURTHER RESEARCH

From this study it has become apparent that further study is needed in the area of cause and effect of the water temperature and the increased fecal coliform levels. There is a need to refine the septic properties map by acquiring water bill data that would be more accurate in determining the properties that are on the sewer system and those with individual waste treatment or septic systems. Expanding the research to look at other river basins in the county to better support or reject the conclusions made in this study. I would also be beneficial to determine the land use categories for the two Landsat images used in this study to quantify the changes in land use as well as NDVI for the entire county. To gain a better understanding of the density of the septic systems within the county it would be beneficial to determine the individual septic densities for the various sub-basins for the Yellow and Alcovy River basins. This would allow better correlation of the water quality measures to the septic system densities for these sub-basins.

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Appendix A – Tables of standard statistics for the 8 collecting localities from the Yellow and Alcovy River Basins.

Table A1. Statistics for Little Suwannee Creek near Lawrenceville, GA, Station Y1, USGS station #2205130.

		Water Temperature (°C)	Air Temperature (°C)	Barometric Pressure (mm Hg)	Specific Conductance	Hydrogen Ion	Dissolved Oxygen	Dissolved Oxygen Percent	Field pH	Fecal Coliform
N	Valid	16	16	16	16	16	16	16	16	16
	Missing	0	0	0	0	0	0	0	0	0
Mean		15.2	17.8	745.1	76.5	0.00012	8.9	89.4	7.0	1228.8
Median		14.5	17.5	745.5	74.0	0.00009	8.7	92.0	7.1	490.0
Mode		6.6	13.5	748.0	74.0	0.00005	7.8	87.0	7.1	490.0
Std. Deviation		6.0	8.0	6.0	6.6	0.00008	1.3	8.1	0.3	1504.8
Skewness		0.1	0.4	-0.3	0.6	2.09	0.2	-0.8	-0.7	1.8
Kurtosis		-1.5	-0.9	-0.7	-0.7	5.03	-0.8	-0.04	0.7	2.9
Minimum		6.6	7.0	735.0	68.0	0.00004	6.8	71.0	6.4	60.0
Maximum		23.1	32.0	755.0	90.0	0.00037	11.3	99.0	7.4	5400.0

		Rain on day of reading (mm)	Total Rain 7-day prior (mm)	Total Rain 14-day prior (mm)	Total Rain 21-day prior (mm)	Total Rain 28-day prior (mm)	Days of Rain 7-day prior	Days of Rain 14-day prior	Days of Rain 21-day prior	Days of Rain 28-day prior
N	Valid	16	16	16	16	16	16	16	16	16
	Missing	0	0	0	0	0	0	0	0	0
Mean		1.0	20.3	49.1	74.1	100.2	1.5	3.2	5.1	7.2
Median		0	7.7	63.2	75.8	108.7	1.0	3.5	6.0	7.0
Mode		0	0	0	63.5	43.9	1.0	5.0	6.0	7.0
Std. Deviation		2.4	24.7	33.4	29.7	30.3	1.3	2.0	2.2	2.6
Skewness		2.5	1.2	-0.2	-0.7	-0.5	0.5	-0.4	-0.7	-0.8
Kurtosis		5.8	0.2	-1.3	0.02	-1.2	-0.8	-1.3	-0.3	1.3
Minimum		0	0	0	8.4	43.9	0	0	1	1
Maximum		8.1	74.2	99.6	114.3	135.7	4	6	8	11

Table A1. (continued)

		Rain for week 1 (mm)	Rain for week 2 (mm)	Rain for week 3 (mm)	Rain for week 4 (mm)	Days of rain week 1	Days of rain week 2	Days of rain week 3	Days of rain week 4
N	Valid	16	16	16	16	16	16	16	16
	Missing	0	0	0	0	0	0	0	0
Mean		20.3	28.9	24.9	26.1	1.5	1.7	1.9	2.1
Median		7.7	20.1	21.0	21.3	1.0	2.0	2.0	2.0
Mode		0.0	0.0	14.7	0.0	1.0	0.0	2.0	2.0
Std. Deviation		24.7	28.0	18.6	22.7	1.3	1.7	0.9	1.4
Skewness		1.2	0.3	1.3	0.4	0.5	0.6	0.1	0.5
Kurtosis		0.2	-1.8	1.2	-1.2	-0.8	-0.7	1.3	-0.3
Minimum		0.0	0.0	0.0	0.0	0	0	0	0
Maximum		74.2	66.6	66.6	66.3	4	5	4	5

		Average Total rainfall 7-day (mm/day)	Average Total rainfall 14-day (mm/day)	Average Total rainfall 21-day (mm/day)	Average Total rainfall 28-day (mm/day)	Average rainfall week 1	Average rainfall week 2	Average rainfall week 3	Average rainfall week 4
N	Valid	12	14	16	16	12	10	15	14
	Missing	4	2	0	0	4	6	1	2
Mean		15.1	20.0	19.5	17.1	15.1	20.9	15.8	11.9
Median		8.3	13.0	15.0	14.0	8.3	14.3	11.2	12.1
Mode		1.3	63.5	63.5	7.3	1.3	3.8	7.4	0.5
Std. Deviation		17.7	19.4	18.0	13.0	17.7	18.1	15.4	6.7
Skewness		2.1	1.8	2.1	3.4	2.1	1.6	2.4	0.3
Kurtosis		5.1	2.5	3.6	12.5	5.1	2.8	6.7	0.003
Minimum		1.3	3.8	2.8	7.3	1.3	3.8	2.8	0.5
Maximum		63.5	63.5	63.5	63.5	63.5	63.5	63.5	25.7

Table A1. (continued)

		Amount of rainfall for first rain prior (mm)	Days prior to reading	Duration of first rainfall (days)	Average first rainfall (mm/day)
N	Valid	16	16	16	16
	Missing	0	0	0	0
Mean		27.1	5.4	1.8	6.6
Median		22.7	3.0	1.0	4.6
Mode		63.5	3.0	1.0	0.4
Std. Deviation		24.0	5.2	1.1	7.3
Skewness		0.6	1.0	1.3	1.8
Kurtosis		-1.3	-0.2	0.7	2.7
Minimum		2.5	0	1	0.4
Maximum		63.5	16	4	25.4

Table A2. Statistics for Pew Creek at Patterson Road near Lawrenceville, GA, Station Y2, USGS Station #2205522.

		Water Temperature (°C)	Air Temperature (°C)	Barometric Pressure (mm Hg)	Specific Conductance	Hydrogen Ion	Dissolved Oxygen	Dissolved Oxygen Percent	Field pH	Fecal Coliform
N	Valid	79	16	65	79	76	76	75	76	89
	Missing	11	74	25	11	14	14	15	14	1
Mean		14.7	21.3	744.3	102.0	0.0002	9.1	89.3	6.9	780
Median		14.7	21.3	745.0	106.0	0.0001	8.8	89.0	6.9	230
Mode		18.5	11.0	745.0	107.0	0.0001	7.5	96.0	7.0	170
Std. Deviation		6.2	6.1	5.1	14.7	0.0003	2.0	11.6	0.4	1869.3
Skewness		-0.1	-0.1	0.1	-1.3	3.5	0.6	0.7	-0.8	4.5
Kurtosis		-1.2	-1.2	-0.03	1.4	14.3	0.1	3.5	0.9	21.7
Minimum		1.2	11.0	733	59	0.00003	6.0	55.0	5.8	20
Maximum		24.4	30.0	757	123	0.00175	15.5	137.0	7.6	12000

		Total Coliform	E. coli	Turbidity	Gage height (ft)	Gage height (m)	Discharge (ft^3/sec)	Instantaneous discharge (ft^3/sec)	Discharge (m^3/sec)	Instantaneous discharge (m^3/sec)
N	Valid	59	59	63	57	57	11	60	11	60
	Missing	31	31	27	33	33	79	30	79	30
Mean		16332.4	592.3	10.9	3.3	1.0	16.0	8.2	0.5	0.2
Median		9200	240.0	4.7	3.7	1.1	3.5	3.3	0.1	0.1
Mode		11000	120.0	3.3	3.7	1.1	1.9	1.2	0.1	0.03
Std. Deviation		33406.0	1092.0	22.2	1.0	0.3	30.8	20.4	0.9	0.6
Skewness		5.6	4.2	5.1	-0.2	-0.2	2.9	6.2	2.9	6.2
Kurtosis		35.7	21.2	28.6	-0.1	-0.1	8.7	42.0	8.7	42.1
Minimum		470	37	1.1	1.8	0.5	1.8	1.1	0.1	0.03
Maximum		240000	7000	150.0	6.4	2.0	105.0	151.0	3.0	4.3

Table A2. (continued)

		Rain on day of reading (mm)	Total Rain 7-day prior (mm)	Total Rain 14-day prior (mm)	Total Rain 21-day prior (mm)	Total Rain 28-day prior (mm)	Days of Rain 7-day prior	Days of Rain 14-day prior	Days of Rain 21-day prior	Days of Rain 28-day prior
N	Valid	90	90	90	90	90	90	90	90	90
	Missing	0	0	0	0	0	0	0	0	0
Mean		4.3	23.3	46.3	66.3	88.5	2.2	4.4	6.4	8.5
Median		0	16.3	36.7	55.5	83.3	2.0	4.0	6.0	9.0
Mode		0	0	73.9	16.0	127.2	2.0	5.0	6.0	9.0
Std. Deviation		10.2	28.9	34.7	43.1	50.2	1.4	1.8	2.1	2.5
Skewness		2.6	2.5	1.3	1.0	0.8	0.3	-0.002	-0.1	0.2
Kurtosis		6.0	8.7	2.1	0.7	0.1	-0.3	0.2	0.1	1.3
Minimum		0	0	0	8.4	15.3	0	0	1	1
Maximum		40.4	172	176	201.5	231.9	6	9	11	16

		Rain for week 1 (mm)	Rain for week 2 (mm)	Rain for week 3 (mm)	Rain for week 4 (mm)	Days of rain week 1	Days of rain week 2	Days of rain week 3	Days of rain week 4
N	Valid	90	90	90	90	90	90	90	90
	Missing	0	0	0	0	0	0	0	0
Mean		23.3	23.0	20.0	22.2	2.2	2.1	2.1	2.1
Median		16.3	14.9	14.7	14.7	2.0	2.0	2.0	2.0
Mode		0	0	0	0	2.0	2.0	2.0	1.0
Std. Deviation		28.9	24.9	19.8	22.5	1.4	1.4	1.3	1.4
Skewness		2.5	1.5	1.2	1.0	0.3	0.2	0.4	0.6
Kurtosis		8.7	3.1	0.7	-0.02	-0.3	-0.8	-0.3	-0.3
Minimum		0	0	0	0	0	0	0	0
Maximum		172.0	134.1	77.2	79.3	6	5	5	6

Table A2. (continued)

		Average Total rainfall 7-day (mm/day)	Average Total rainfall 14-day (mm/day)	Average Total rainfall 21-day (mm/day)	Average Total rainfall 28-day (mm/day)	Average rainfall week 1	Average rainfall week 2	Average rainfall week 3	Average rainfall week 4
N	Valid	80	88	90	90	79	77	81.9	81
	Missing	10	2	0	0	11	13	9	6
Mean		10.3	11.8	11.2	10.8	10.4	11.2	10.0	10.4
Median		6.5	8.2	8.6	9.3	6.6	7.4	7.5	8.0
Mode		17.5	14.8	15.9	14.1	17.5	4.1	7.4	8.0
Std. Deviation		11.8	11.5	9.9	7.6	11.8	11.9	9.8	8.2
Skewness		2.4	3.0	3.5	4.0	2.4	2.3	2.7	1.1
Kurtosis		6.9	10.1	16.3	25.8	6.8	5.9	11.0	1.2
Minimum		0	0.3	2.0	2.0	0.0	0.0	0.0	0.0
Maximum		63.5	63.5	63.5	63.5	63.5	63.5	63.5	38.6

		Amount of rainfall for first rain prior (mm)	Days prior to reading	Duration of first rainfall (days)	Average first rainfall (mm/day)
N	Valid	90	90	90	90
	Missing	0	0	0	0
Mean		21.1	2.8	1.9	12.1
Median		12.1	2.0	1.0	6.5
Mode		0.0	0.0	1.0	0.0
Std. Deviation		26.7	3.5	1.3	14.4
Skewness		3.1	1.8	1.8	2.1
Kurtosis		13.5	3.1	2.7	4.4
Minimum		0.0	0	1	0.03
Maximum		172.0	16	6	63.5

Table A3. Statistics for the Yellow River near Snellville, GA, Station Y3, USGS Station #2206500.

		Water Temperature (°C)	Air Temperature (°C)	Barometric Pressure (mm Hg)	Specific Conductance	Hydrogen Ion	Dissolved Oxygen	Biochemical Oxygen Demand	Field pH	Fecal Coliform
N	Valid	136	128	99	143	141	136	143	141	153
	Missing	17	25	54	10	12	17	10	12	0
Mean		15.5	15.9	744.5	116.4	0.00009	8.8	1.3	7.1	4010.8
Median		16.0	16.5	744.0	102.0	0.00008	8.5	1.0	7.1	490.0
Mode		16.0	14.0	742.0	60.0	0.00008	7.2	1.0	7.0	430.0
Std. Deviation		6.1	8.1	5.7	56.5	0.00008	1.6	1.0	0.2	12319.9
Skewness		-0.2	-0.2	0.7	1.0	6.3	0.4	2.4	-0.7	5.6
Kurtosis		-1.1	-0.6	1.5	0.7	55.1	-0.8	7.3	2.5	35.8
Minimum		2.0	-4.0	732	47.0	0.00003	6.1	0.2	6.1	20.0
Maximum		25.0	32.0	762	299.0	0.0008	13.0	6.0	7.6	93000.0

		Gage height (ft)	Discharge (ft^3/sec)	Discharge (m^3/sec)	Carbon Dioxide (mg/L)	Turbidity	Color of water (Pt-Co units)
N	Valid	132	145	145	75	80	38
	Missing	21	8	8	78	73	115
Mean		2.0	184.0	5.2	4.6	28.8	71.2
Median		1.9	135.0	3.8	3.9	15.0	55.0
Mode		1.5	255.0	7.2	3.9	6.0	60.0
Std. Deviation		0.7	204.2	5.8	3.5	36.0	68.9
Skewness		3.6	5.0	5.0	3.2	2.8	2.6
Kurtosis		20.8	33.6	33.7	13.7	9.6	7.6
Minimum		1.1	19.0	0.5	1.0	1.0	10.0
Maximum		7.1	1800.0	51.0	23.0	210.0	350.0

Table A3. (continued)

		Nitrate plus Nitrite (mg/L)	Phosphorus, unfiltered (mg/L)	Organic Carbon (mg/L)	Acid neutralizing capacity (field)	Acid neutralizing capacity (lab)	Ammonia plus organic nitrogen (mg/L)
N	Valid	138	138	133	47	58	136
	Missing	15	15	20	106	95	15
Mean		1.1	0.1	3.8	21.5	33.2	0.1
Median		0.9	0.1	3.0	21.0	31.5	0.04
Mode		0.2	0.1	3.0	19.0	25.0	0.03
Std. Deviation		0.8	0.1	2.7	4.7	10.0	0.2
Skewness		1.8	4.0	2.4	0.2	0.4	6.3
Kurtosis		5.6	22.1	7.0	0.4	-0.7	49.4
Minimum		0.2	0.03	1.0	10.0	16.0	0.02
Maximum		5.0	0.7	17.2	34.0	53.0	1.7

		Rain on day of reading (mm)	Total Rain 7-day prior (mm)	Total Rain 14-day prior (mm)	Total Rain 21-day prior (mm)	Total Rain 28-day prior (mm)	Days of Rain 7-day prior	Days of Rain 14-day prior	Days of Rain 21-day prior	Days of Rain 28-day prior
N	Valid	153	153	153	153	153	153	153	153	153
	Missing	0	0	0	0	0	0	0	0	0
Mean		2.3	24.1	51.2	78.4	102.4	1.9	4.0	6.0	7.9
Median		0	18.3	46.0	65.8	93.4	2.0	4.0	6.0	8.0
Mode		0	0	0	0	0	1.0	2.0	5.0	8.0
Std. Deviation		6.3	24.8	40.9	55.4	64.0	1.4	2.3	3.2	3.9
Skewness		3.9	1.6	1.1	1.1	0.6	0.5	0.5	0.5	0.5
Kurtosis		17.7	3.6	1.5	1.6	0.2	-0.3	-0.1	0.2	0.5
Minimum		0	0	0	0	0	0	0	0	0
Maximum		43.2	147.3	215.7	302.8	314.7	6	11	17	22

Table A3. (continued)

		Rain for week 1 (mm)	Rain for week 2 (mm)	Rain for week 3 (mm)	Rain for week 4 (mm)	Days of rain week 1	Days of rain week 2	Days of rain week 3	Days of rain week 4
N	Valid	153	153	153	153	153	153	153	153
	Missing	0	0	0	0	0	0	0	0
Mean		24.1	27.1	27.2	24.0	1.9	2.0	2.1	1.9
Median		18.3	18.3	18.8	11.9	2.0	2.0	2.0	2.0
Mode		0	0	0	0	1.0	1.0	2.0	1.0
Std. Deviation		24.8	29.9	28.4	29.6	1.4	1.6	1.6	1.6
Skewness		1.6	1.5	1.5	1.6	0.5	0.6	0.5	0.6
Kurtosis		3.6	2.3	2.6	2.7	-0.3	-0.5	-0.4	-0.5
Minimum		0	0	0	0	0	0	0	0
Maximum		147.3	152.4	150.6	140.5	6	6	6	6

		Average Total rainfall 7-day (mm/day)	Average Total rainfall 14-day (mm/day)	Average Total rainfall 21-day (mm/day)	Average Total rainfall 28-day (mm/day)	Average rainfall week 1	Average rainfall week 2	Average rainfall week 3	Average rainfall week 4
N	Valid	126	147	149	151	126	126	125	118
	Missing	27	6	4	2	27	27	28	35
Mean		12.6	12.8	13.0	12.8	12.6	13.2	12.9	11.8
Median		10.5	12.2	12.5	12.7	10.5	10.8	10.8	9.1
Mode		2.5	3.8	8.3	12.3	2.5	2.5	6.4	0
Std. Deviation		9.3	7.7	6.2	5.2	9.3	9.8	9.2	10.3
Skewness		1.2	1.2	0.9	0.2	1.2	1.3	1.2	1.7
Kurtosis		1.9	2.4	2.1	-0.3	1.9	2.5	2.2	4.0
Minimum		0.3	0.3	0.7	1.3	0.3	0.3	0	0
Maximum		51.6	44.1	41.0	25.4	51.6	51.1	50.2	61.2

Table A3. (continued)

		Amount of rainfall for first rain prior (mm)	Days prior to reading	Duration of first rainfall (days)	Average first rainfall (mm/day)
N	Valid	153	153	153	153
	Missing	0	0	0	0
Mean		24.5	3.8	1.9	12.4
Median		18.5	2.0	2.0	10.7
Mode		2.5	0	1.0	2.5
Std. Deviation		22.5	5.2	1.1	9.6
Skewness		1.4	3.7	1.7	1.4
Kurtosis		2.2	20.9	3.4	2.5
Minimum		0.3	0	1	0.3
Maximum		115.1	42	7	51.6

Table A4. Statistics for the Yellow River at GA 124 near Lithonia, GA, Station Y4, USGS Station #2207120.

		Water Temperature (°C)	Air Temperature (°C)	Barometric Pressure (mm Hg)	Specific Conductance	Hydrogen Ion	Dissolved Oxygen	Dissolved Oxygen Percent	Field pH	Fecal Coliform
N	Valid	33	31	33	32	32	33	33	32	34
	Missing	2	4	2	3	3	2	2	3	1
Mean		17.4	21.3	724.5	145.4	0.0003	8.8	92.5	6.9	5710.6
Median		17.5	22.0	745.0	135.0	0.0001	8.4	93.0	7.0	180.0
Mode		17.0	31.0	750.0	63.0	0.00004	6.7	93.0	7.0	52.0
Std. Deviation		6.2	7.3	114.2	44.3	0.0006	2.0	11.5	0.5	17665.2
Skewness		-0.6	-0.6	-5.7	0.2	4.9	0.9	0.004	-0.5	4.9
Kurtosis		-0.2	-0.1	32.9	-0.4	25.7	0.6	-0.1	0.9	26.3
Minimum		3.0	5.0	89.0	63.0	0.00001	5.4	66.0	5.5	44
Maximum		25.8	32.5	751.0	247.0	0.00334	14.0	116.0	7.9	100000

		Total Coliform	Biochemical Oxygen Demand	Chemical Oxygen Demand	Gage height (ft)	Gage height (m)	Instantaneous discharge (ft^3/sec)	Instantaneous discharge (m^3/sec)	Turbidity	Specific Conductance Lab
N	Valid	34	32	31	32	32	30	31	30	20
	Missing	1	3	4	3	3	5	4	5	15
Mean		26291.8	2.2	17.5	4.7	1.4	667.5	18.3	90.5	153.1
Median		1700.0	1.1	11.0	3.8	1.2	253.5	6.8	14.0	160.5
Mode		170.0	0.7	5.0	3.6	1.1	466.0	13.2	14.0	64.0
Std. Deviation		53842.6	2.0	26.3	1.8	0.6	820.9	23.1	166.2	57.2
Skewness		2.7	1.4	4.6	1.3	1.3	1.7	1.7	3.2	0.3
Kurtosis		7.5	1.1	23.0	0.7	0.7	1.9	2.1	12.7	0.2
Minimum		56	0.5	5.0	3.0	0.9	70.0	1.7	1.6	64.0
Maximum		230000	7.4	150.0	9.4	2.9	2970.0	84.1	820.0	290.0

Table A4. (continued)

		Suspended solids (mg/L)	Total Nitrogen (mg/L)	Ammonia plus organic Nitrogen (mg/L)	Nitrate plus Nitrite (mg/L)	Phosphorus filtered (mg/L)	Phosphorus unfiltered (mg/L)	Calcium unfiltered (mg/L)	Magnesium unfiltered (mg/L)	Cadmium unfiltered (μg/L)
N	Valid	34	32	35	35	35	35	22	22	35
	Missing	1	3	0	0	0	0	13	13	0
Mean		145.2	2.3	0.7	1.5	0.1	0.02	11.1	2.7	0.5
Median		10.5	2.3	0.4	1.4	0.04	0.02	11.0	2.6	0.5
Mode		6.0	1.6	0.3	1.4	0.02	0.02	12.0	2.6	0.5
Std. Deviation		261.0	0.7	0.7	0.8	0.1	0.01	3.6	0.6	0.1
Skewness		3.0	1.1	1.9	1.1	2.0	1.6	1.2	2.7	3.1
Kurtosis		11.3	1.4	3.8	2.4	4.3	2.2	2.6	10.8	8.0
Minimum		1.0	1.2	0.2	0.0	0.01	0.01	6.4	1.8	0.5
Maximum		1300.0	4.5	3.2	4.2	0.6	0.1	22.0	5.1	1.0

		Chromium unfiltered (μg/L)	Copper unfiltered (μg/L)	Iron unfiltered (μg/L)	Lead unfiltered (μg/L)	Manganese unfiltered (μg/L)	Zinc unfiltered (μg/L)	Dissolved Solids dried (mg/L)	Total Nitrogen unfiltered (mg/L)
N	Valid	33	35	9	34	9	35	35	32
	Missing	2	0	26	1	26	0	0	3
Mean		4.5	4.4	3781.2	4.8	347.3	31.9	90.0	10.1
Median		1.0	1.0	554.0	1.0	92.0	15.0	88.0	9.9
Mode		1.0	1.0	368.0	1.0	59.0	9.0	52.0	8.0
Std. Deviation		7.0	6.4	5731.5	8.3	591.0	38.0	30.1	3.3
Skewness		3.2	3.3	1.5	2.7	2.3	3.0	0.5	1.1
Kurtosis		12.5	13.2	0.5	7.7	5.4	11.0	-0.1	1.5
Minimum		1.0	1.0	368.0	0.2	59.0	8.0	44.0	5.4
Maximum		36.0	34.0	13900.0	38.0	1800.0	200.0	170.0	20.0

Table A4. (continued)

		Rain on day of reading (mm)	Total Rain 7-day prior (mm)	Total Rain 14-day prior (mm)	Total Rain 21-day prior (mm)	Total Rain 28-day prior (mm)	Days of Rain 7-day prior	Days of Rain 14-day prior	Days of Rain 21-day prior	Days of Rain 28-day prior
N	Valid	35	35	35	35	35	35	35	35	35
	Missing	0	0	0	0	0	0	0	0	0
Mean		14.1	28.0	51.4	78.3	106.0	1.8	3.7	6.0	8.3
Median		0	17.0	55.6	70.4	98.1	2.0	3.0	6.0	8.0
Mode		0	0	2.3	4.8	25.4	1.0	2.0	6.0	10.0
Std. Deviation		20.8	27.0	30.5	38.7	46.4	1.3	1.8	2.2	2.7
Skewness		1.2	0.7	0.3	0.7	0.5	0.5	0.5	0.7	0
Kurtosis		0.2	-0.7	-0.7	0.6	0	-0.4	-0.4	2.0	-0.7
Minimum		0	0	2.3	4.8	25.4	0	1	2	3
Maximum		67.8	94.2	115.1	181.1	226.6	5	8	13	14

		Rain for week 1 (mm)	Rain for week 2 (mm)	Rain for week 3 (mm)	Rain for week 4 (mm)	Days of rain week 1	Days of rain week 2	Days of rain week 3	Days of rain week 4
N	Valid	35	35	35	35	35	35	35	35
	Missing	0	0	0	0	0	0	0	0
Mean		28.0	23.4	26.9	27.6	1.8	1.9	2.3	2.3
Median		17.0	18.5	24.1	16.8	2.0	2.0	2.0	2.0
Mode		0	0	0	0	1.0	2.0	1.0	1.0
Std. Deviation		27.0	26.6	25.5	29.1	1.3	1.1	1.6	1.5
Skewness		0.7	1.9	1.3	1.8	0.5	0.4	0.4	0.2
Kurtosis		-0.7	3.5	2.2	3.7	-0.4	0.5	-1.2	-1.3
Minimum		0	0	0	0	0	0	0	0
Maximum		94.2	104.7	110.8	126.0	5	5	5	5

Table A4. (continued)

		Average Total rainfall 7-day (mm/day)	Average Total rainfall 14-day (mm/day)	Average Total rainfall 21-day (mm/day)	Average Total rainfall 28-day (mm/day)	Average rainfall week 1	Average rainfall week 2	Average rainfall week 3	Average rainfall week 4
N	Valid	29	35	35	35	29	32	32	33
	Missing	6	0	0	0	6	3	3	2
Mean		16.0	15.3	14.2	13.4	16.0	11.9	12.4	12.1
Median		13.8	14.0	13.8	11.8	13.8	9.5	10.6	11.7
Mode		1.3	1.0	1.0	2.8	1.3	0.8	1.0	1.6
Std. Deviation		13.7	10.3	8.2	6.2	13.7	10.8	10.6	7.9
Skewness		2.0	1.5	1.6	1.6	2.0	1.8	2.1	0.4
Kurtosis		6.2	3.8	3.4	4.4	6.2	4.9	6.4	-0.8
Minimum		1.3	1.0	1.0	2.8	1.3	0.8	0.8	1.6
Maximum		67.8	52.3	42.5	35.8	67.8	52.3	53.3	28.3

		Amount of rainfall for first rain prior (mm)	Days prior to reading	Duration of first rainfall (days)	Average first rainfall (mm/day)
N	Valid	35	35	35	35
	Missing	0	0	0	0
Mean		30.8	3.1	1.6	21.2
Median		28.5	2.0	1.0	16.5
Mode		37.9	0	1.0	37.9
Std. Deviation		25.0	3.6	0.9	17.8
Skewness		1.2	1.0	1.5	1.1
Kurtosis		1.6	0.3	1.6	0.5
Minimum		1.3	0	1	1.3
Maximum		104.7	13	4	67.8

Table A5. Statistics for Hopkins Creek at Stanley Road, near Dacula, GA, Station A1, USGS Station #2208085.

		Water Temperature (°C)	Air Temperature (°C)	Barometric Pressure (mm Hg)	Specific Conductance	Hydrogen Ion	Dissolved Oxygen	Dissolved Oxygen Percent	Field pH	Fecal Coliform
N	Valid	16	16	16	16	16	16	16	16	16
	Missing	0	0	0	0	0	0	0	0	0
Mean		14.3	17.9	745.3	69.1	0.00012	8.6	84.3	7.0	226.9
Median		13.4	16.8	747.0	66.5	0.0001	8.3	83.0	7.1	110.0
Mode		21.7	16.6	747.0	62.0	0.00008	7.7	80.0	7.1	20.0
Std. Deviation		5.7	7.8	5.9	14.5	0.00007	1.4	8.4	0.2	232.5
Skewness		0.1	0.1	-0.7	1.1	2.26	0.4	-0.02	-1.1	1.1
Kurtosis		-1.4	-0.7	0.02	1.5	6.21	-1.1	-1.1	0.5	0.5
Minimum		6.4	6.3	733	50	0.00007	6.6	70	6.5	20.0
Maximum		22.3	31.0	754	106	0.00033	11.1	97	7.1	790.0

		Gage height (ft)	Gage height (m)
N	Valid	16	16
	Missing	0	0
Mean		2.7	0.8
Median		2.7	0.8
Mode		2.7	0.8
Std. Deviation		0.1	0.03
Skewness		0.6	0.6
Kurtosis		-0.7	-0.7
Minimum		2.6	0.8
Maximum		2.9	0.9

Table A5. (continued)

		Rain on day of reading (mm)	Total Rain 7-day prior (mm)	Total Rain 14-day prior (mm)	Total Rain 21-day prior (mm)	Total Rain 28-day prior (mm)	Days of Rain 7-day prior	Days of Rain 14-day prior	Days of Rain 21-day prior	Days of Rain 28-day prior
N	Valid	16	16	16	16	16	16	16	16	16
	Missing	0	0	0	0	0	0	0	0	0
Mean		1.0	20.3	49.1	74.1	100.2	1.5	3.2	5.1	7.2
Median		0	7.7	63.2	75.8	108.7	1.0	3.5	6.0	7.0
Mode		0	0	0	63.5	43.9	1.0	5.0	6.0	7.0
Std. Deviation		2.4	24.7	33.4	29.7	30.3	1.3	2.0	2.2	2.6
Skewness		2.5	1.2	-0.2	-0.7	-0.5	0.5	-0.4	-0.7	-0.8
Kurtosis		5.8	0.2	-1.3	0.02	-1.2	-0.8	-1.3	-0.3	1.3
Minimum		0	0	0	8.4	43.9	0	0	1	1
Maximum		8.1	74.2	99.6	114.3	135.7	4	6	8	11

		Rain for week 1 (mm)	Rain for week 2 (mm)	Rain for week 3 (mm)	Rain for week 4 (mm)	Days of rain week 1	Days of rain week 2	Days of rain week 3	Days of rain week 4
N	Valid	16	16	16	16	16	16	16	16
	Missing	0	0	0	0	0	0	0	0
Mean		20.3	28.9	24.9	26.1	1.5	1.7	1.9	2.1
Median		7.7	20.1	21.0	21.3	1.0	2.0	2.0	2.0
Mode		0	0	14.7	0	1.0	0	2.0	2.0
Std. Deviation		24.7	28.0	18.6	22.7	1.3	1.7	0.9	1.4
Skewness		1.2	0.3	1.3	0.4	0.5	0.6	0.1	0.5
Kurtosis		0.2	-1.8	1.2	-1.2	-0.8	-0.7	1.3	-0.3
Minimum		0	0	0	0	0	0	0	0
Maximum		74.2	66.6	66.6	66.3	4	5	4	5

Table A5. (continued)

		Average Total rainfall 7-day (mm/day)	Average Total rainfall 14-day (mm/day)	Average Total rainfall 21-day (mm/day)	Average Total rainfall 28-day (mm/day)	Average rainfall week 1	Average rainfall week 2	Average rainfall week 3	Average rainfall week 4
N	Valid	12	14	16	16	12	10	15	14
	Missing	4	2	0	0	4	6	1	2
Mean		15.1	20.0	19.5	17.1	15.1	20.9	15.8	11.9
Median		8.3	13.0	15.0	14.0	8.3	14.3	11.2	12.1
Mode		1.3	63.5	63.5	7.3	1.3	3.8	7.4	0.5
Std. Deviation		17.7	19.4	18.0	13.0	17.7	18.1	15.4	6.7
Skewness		2.1	1.8	2.1	3.4	2.1	1.6	2.4	0.3
Kurtosis		5.1	2.5	3.6	12.5	5.1	2.8	6.7	0.003
Minimum		1.3	3.8	2.8	7.3	1.3	3.8	2.8	0.5
Maximum		63.5	63.5	63.5	63.5	63.5	63.5	63.5	25.7

		Amount of rainfall for first rain prior (mm)	Days prior to reading	Duration of first rainfall (days)	Average first rainfall (mm/day)
N	Valid	16	16	16	16
	Missing	0	0	0	0
Mean		27.1	5.4	1.8	6.6
Median		22.7	3.0	1.0	4.6
Mode		63.5	3.0	1.0	0.4
Std. Deviation		24.0	5.2	1.1	7.3
Skewness		0.6	1.0	1.3	1.8
Kurtosis		-1.3	-0.2	0.7	2.7
Minimum		2.5	0	1	0.4
Maximum		63.5	16	4	25.4

Table A6. Statistics for Shoal Creek at Paper Mill Road, near Lawrenceville, GA, Station A2, USGS Station #2208130.

		Water Temperature (°C)	Barometric Pressure (mm Hg)	Specific Conductance	Hydrogen Ion	Dissolved Oxygen	Dissolved Oxygen Percent	Field pH	Fecal Coliform
N	Valid	52	49	52	52	52	50	52	70
	Missing	18	21	18	18	18	20	18	0
Mean		13.0	742.0	80.4	0.00024	10.0	95.5	6.8	737.7
Median		12.6	742.0	83.0	0.00012	10.3	95.5	6.9	200.0
Mode		12.6	740.0	83.0	0.0001	9.8	83.0	7.0	100.0
Std. Deviation		6.1	5.0	9.9	0.00029	2.2	17.2	0.4	1855.4
Skewness		0.3	0.1	-1.4	3.0	-0.2	0.03	0.2	5.0
Kurtosis		-0.8	-0.2	2.7	8.9	-0.7	3.6	3.3	29.0
Minimum		1.5	732	49.0	0.00005	4.9	49	5.9	1.0
Maximum		26.2	755	100.0	0.00136	14.6	154	8.3	13000

		Total Coliform	E. coli	Gage height (ft)	Gage height (m)	Discharge (ft^3/sec)	Instantaneous discharge (ft^3/sec)	Discharge (m^3/sec)	Instantaneous discharge (m^3/sec)
N	Valid	59	59	39	39	12	52	12	52
	Missing	11	11	31	31	58	18	58	18
Mean		9388.3	1030.2	2.1	0.6	9.9	3.1	0.3	0.1
Median		5300.0	180.0	2.0	0.6	9.5	2.2	0.3	0.1
Mode		10000.0	180.0	1.9	0.6	9.1	1.8	0.3	0.03
Std. Deviation		10412.7	5057.0	0.3	0.1	5.0	3.1	0.1	0.1
Skewness		2.4	7.6	1.8	1.8	0.7	3.0	0.7	3.0
Kurtosis		7.3	57.6	3.8	3.7	0.04	10.9	0.1	10.9
Minimum		260	21	1.9	0.6	3.7	0.4	0.1	0.01
Maximum		55000	39000	3.2	1.0	20.0	18.0	0.6	0.5

Table A6. (continued)

		Rain on day of reading (mm)	Total Rain 7-day prior (mm)	Total Rain 14-day prior (mm)	Total Rain 21-day prior (mm)	Total Rain 28-day prior (mm)	Days of Rain 7-day prior	Days of Rain 14-day prior	Days of Rain 21-day prior	Days of Rain 28-day prior
N	Valid	70	70	70	70	70	70	70	70	70
	Missing	0	0	0	0	0	0	0	0	0
Mean		4.1	22.6	44.1	64.3	85.5	2.2	4.5	6.7	8.7
Median		0	14.3	33.4	51.9	74.7	2.0	4.0	6.0	9.0
Mode		0	0	61.0	16.0	90.2	2.0	4.0	5.0	9.0
Std. Deviation		9.6	29.6	33.1	44.9	51.6	1.3	1.7	1.9	2.3
Skewness		2.7	2.9	1.5	1.1	0.8	0.3	0.2	0.3	0.7
Kurtosis		6.4	10.9	3.3	0.9	0.05	-0.05	0.1	-0.5	1.0
Minimum		0	0	0.5	9.9	15.3	0	1	3	4
Maximum		40.4	172.0	176.0	201.5	231.9	6	8	11	16

		Rain for week 1 (mm)	Rain for week 2 (mm)	Rain for week 3 (mm)	Rain for week 4 (mm)	Days of rain week 1	Days of rain week 2	Days of rain week 3	Days of rain week 4
N	Valid	70	70	70	70	70	70	70	70
	Missing	0	0	0	0	0	0	0	0
Mean		22.6	21.5	20.2	21.2	2.2	2.3	2.1	2.1
Median		14.3	17.0	10.9	12.3	2.0	2.0	2.0	2.0
Mode		0	0	0	0	2.0	2.0	2.0	1.0
Std. Deviation		29.6	20.7	21.1	22.3	1.3	1.4	1.4	1.4
Skewness		2.9	0.9	1.1	1.2	0.3	0.4	0.4	0.6
Kurtosis		10.9	-0.3	0.3	0.5	-0.05	-0.7	-0.7	-0.2
Minimum		0	0	0	0	0	0	0	0
Maximum		172.0	76.7	77.2	79.3	6	5	5	6

Table A6. (continued)

		Average Total rainfall 7-day (mm/day)	Average Total rainfall 14-day (mm/day)	Average Total rainfall 21-day (mm/day)	Average Total rainfall 28-day (mm/day)	Average rainfall week 1	Average rainfall week 2	Average rainfall week 3	Average rainfall week 4
N	Valid	64	70	70	70	63	62	62	63
	Missing	6	0	0	0	7	8	8	7
Mean		9.4	10.2	9.4	9.5	9.6	9.6	9.3	10.2
Median		6.5	7.7	7.5	8.4	6.6	7.0	7.3	7.5
Mode		0.03	7.8	11.1	10.0	0.03	6.4	4.4	1.8
Std. Deviation		10.5	8.7	5.6	4.8	10.5	9.0	8.3	8.6
Skewness		2.3	2.8	1.3	0.9	2.3	2.2	1.6	1.3
Kurtosis		5.9	10.1	2.1	1.1	5.8	6.8	2.6	1.4
Minimum		0	0.3	2.0	2.0	0	0	0	0
Maximum		51.3	51.3	28.8	26.2	51.3	51.3	38.6	38.6

		Amount of rainfall for first rain prior (mm)	Days prior to reading	Duration of first rainfall (days)	Average first rainfall (mm/day)
N	Valid	70	70	70	70
	Missing	0	0	0	0
Mean		19.4	2.3	1.9	10.4
Median		10.5	1.0	1.0	6.2
Mode		0	0	1.0	0
Std. Deviation		27.6	2.9	1.3	11.5
Skewness		3.6	1.6	1.8	1.8
Kurtosis		16.6	2.1	2.8	2.9
Minimum		0	0	1	0
Maximum		172.0	11	6	51.3

Table A7. Statistics for Shoal Creek near Lawrenceville, GA, Station A3 USGS Station #2208140.

		Water Temperature (^oC)	Air Temperature (^oC)	Barometric Pressure (mm Hg)	Specific Conductance	Hydrogen Ion	Dissolved Oxygen	Dissolved Oxygen Percent	Field pH	Fecal Coliform
N	Valid	16	16	16	16	16	16	16	16	16
	Missing	0	0	0	0	0	0	0	0	0
Mean		14.5	18.8	746.9	66.1	0.00012	8.8	87.4	7.0	646.3
Median		13.2	18.8	747.5	66.5	0.00011	9.0	89.5	7.0	410.0
Mode		6.0	7.3	747.0	67.0	0.00008	10.2	96.0	7.1	790.0
Std. Deviation		5.8	7.7	5.0	4.5	0.00005	1.4	8.4	0.2	649.6
Skewness		0.1	0.1	-1.0	-0.2	1.3	-0.4	-1.9	-0.6	1.4
Kurtosis		-1.3	-1.0	0.8	0.5	1.2	-0.6	5.2	-0.5	2.2
Minimum		6.0	7.3	735	57	0.00006	5.9	62	6.6	20
Maximum		22.8	31.4	754	75	0.00024	10.8	96	7.2	2400

		Gage height (ft)	Gage height (m)
N	Valid	16	16
	Missing	0	0
Mean		2.0	0.6
Median		1.9	0.6
Mode		1.9	0.6
Std. Deviation		0.2	0.05
Skewness		1.3	1.3
Kurtosis		2.4	2.4
Minimum		1.8	0.5
Maximum		2.4	0.7

Table A7. (continued)

		Rain on day of reading (mm)	Total Rain 7-day prior (mm)	Total Rain 14-day prior (mm)	Total Rain 21-day prior (mm)	Total Rain 28-day prior (mm)	Days of Rain 7-day prior	Days of Rain 14-day prior	Days of Rain 21-day prior	Days of Rain 28-day prior
N	Valid	16	16	16	16	16	16	16	16	16
	Missing	0	0	0	0	0	0	0	0	0
Mean		1.0	20.3	49.1	74.1	100.2	1.5	3.2	5.1	7.2
Median		0	7.7	63.2	75.8	108.7	1.0	3.5	6.0	7.0
Mode		0	0	0	63.5	43.9	1.0	5.0	6.0	7.0
Std. Deviation		2.4	24.7	33.4	29.7	30.3	1.3	2.0	2.2	2.6
Skewness		2.5	1.2	-0.2	-0.7	-0.5	0.5	-0.4	-0.7	-0.8
Kurtosis		5.8	0.2	-1.3	0.02	-1.2	-0.8	-1.3	-0.3	1.3
Minimum		0	0	0	8.4	43.9	0	0	1	1
Maximum		8.1	74.2	99.6	114.3	135.7	4	6	8	11

		Rain for week 1 (mm)	Rain for week 2 (mm)	Rain for week 3 (mm)	Rain for week 4 (mm)	Days of rain week 1	Days of rain week 2	Days of rain week 3	Days of rain week 4
N	Valid	16	16	16	16	16	16	16	16
	Missing	0	0	0	0	0	0	0	0
Mean		20.3	28.9	24.9	26.1	1.5	1.7	1.9	2.1
Median		7.7	20.1	21.0	21.3	1.0	2.0	2.0	2.0
Mode		0	0	14.7	0	1.0	0	2.0	2.0
Std. Deviation		24.7	28.0	18.6	22.7	1.3	1.7	0.9	1.4
Skewness		1.2	0.3	1.3	0.4	0.5	0.6	0.1	0.5
Kurtosis		0.2	-1.8	1.2	-1.2	-0.8	-0.7	1.3	-0.3
Minimum		0	0	0	0	0	0	0	0
Maximum		74.2	66.6	66.6	66.3	4	5	4	5

Table A7. (continued)

		Average Total rainfall 7-day (mm/day)	Average Total rainfall 14-day (mm/day)	Average Total rainfall 21-day (mm/day)	Average Total rainfall 28-day (mm/day)	Average rainfall week 1	Average rainfall week 2	Average rainfall week 3	Average rainfall week 4
N	Valid	12	14	16	16	12	10	15	14
	Missing	4	2	0	0	4	6	1	2
Mean		15.1	20.0	19.5	17.1	15.1	20.9	15.8	11.9
Median		8.3	13.0	15.0	14.0	8.3	14.3	11.2	12.1
Mode		1.3	63.5	63.5	7.3	1.3	3.8	7.4	0.5
Std. Deviation		17.7	19.4	18.0	13.0	17.7	18.1	15.4	6.7
Skewness		2.1	1.8	2.1	3.4	2.1	1.6	2.4	0.3
Kurtosis		5.1	2.5	3.6	12.5	5.1	2.8	6.7	0.003
Minimum		1.3	3.8	2.8	7.3	1.3	3.8	2.8	0.5
Maximum		63.5	63.5	63.5	63.5	63.5	63.5	63.5	25.7

		Amount of rainfall for first rain prior (mm)	Days prior to reading	Duration of first rainfall (days)	Average first rainfall (mm/day)
N	Valid	16	16	16	16
	Missing	0	0	0	0
Mean		27.1	5.4	1.8	6.6
Median		22.7	3.0	1.0	4.6
Mode		63.5	3.0	1.0	0.4
Std. Deviation		24.0	5.2	1.1	7.3
Skewness		0.6	1.0	1.3	1.8
Kurtosis		-1.3	-0.2	0.7	2.7
Minimum		2.5	0	1	0.4
Maximum		63.5	16	4	25.4

Table A8. Statistics for the Alcovy River at New Hope Road, near Grayson, GA, Station A4, USGS Station #2208150.

		Water Temperature (^oC)	Air Temperature (^oC)	Barometric Pressure (mm Hg)	Specific Conductance	Hydrogen Ion	Dissolved Oxygen	Dissolved Oxygen Percent	Field pH	Fecal Coliform
N	Valid	30	28	29	31	31	29	29	31	30
	Missing	1	3	2	0	0	2	2	0	1
Mean		15.4	18.8	742.6	72.2	.0005	9.3	91.7	6.5	1020.4
Median		16.4	21.3	742.0	69.0	.0003	8.8	88.0	6.5	150.0
Mode		15.0	23.0	740.0	73.0	.0001	6.9	85.0	6.3	72.0
Std. Deviation		6.1	7.2	4.7	26.3	.0003	2.1	11.1	0.4	1711.5
Skewness		-0.8	-1.6	-0.1	4.2	1.1	1.0	2.4	0.2	2.0
Kurtosis		-0.1	2.8	-0.3	21.1	.0.5	0.2	8.5	-0.9	3.3
Minimum		1.0	-4.0	732	46.0	.00008	6.9	78.0	5.9	28
Maximum		23.5	27.5	751	202.0	.00127	14.2	136.0	7.1	6500

		Total Coliform	Biochemical Oxygen Demand	Chemical Oxygen Demand	Gage height (ft)	Gage height (m)	Discharge (ft^3/sec)	Instantaneous discharge (ft^3/sec)	Discharge (m^3/sec)	Turbidity
N	Valid	29	27	29	25	25	9	18	25	28
	Missing	2	4	2	6	6	22	13	6	3
Mean		4647.4	2.1	12.0	3.7	1.1	208.9	134.2	4.8	102.8
Median		670.0	1.5	7.0	3.2	1.0	28.0	44.5	1.1	18.5
Mode		240.0	0.7	5.0	3.4	1.1	795.0	37.0	1.1	14.0
Std. Deviation		8885.4	1.5	11.5	1.5	0.5	335.5	196.6	7.2	144.5
Skewness		3.5	0.5	2.5	1.6	1.6	1.5	2.4	1.9	1.2
Kurtosis		14.1	-1.2	6.2	2.5	2.5	0.6	6.1	2.3	-0.1
Minimum		29	0.5	5.0	1.8	0.5	3.3	3.5	0.1	2.8
Maximum		44000	5.0	52.0	8.1	2.5	795.0	770.0	22.5	420.0

Table A8. (continued)

		Suspended solids (mg/L)	Total Nitrogen (mg/L)	Ammonia plus organic Nitrogen (mg/L)	Nitrate plus Nitrite (mg/L)	Phosphorus filtered (mg/L)	Phosphorus unfiltered (mg/L)	Calcium unfiltered (mg/L)	Magnesium unfiltered (mg/L)	Cadmium unfiltered (μg/L)
N	Valid	29	18	30	30	28	30	23	23	29
	Missing	2	13	1	1	3	1	8	8	2
Mean		193.6	1.5	0.7	0.4	0.02	0.1	5.6	1.8	0.5
Median		12.0	1.4	0.3	0.5	0.02	0.03	5.3	1.7	0.5
Mode		6.0	0.7	0.2	0.5	0.02	0.02	6.1	1.5	0.5
Std. Deviation		305.1	1.1	0.9	0.1	0.01	0.13	1.3	0.6	0
Skewness		2.3	2.8	3.2	-0.1	3.9	2.3	0.4	1.7	
Kurtosis		5.7	9.7	13.0	-0.2	15.8	6.6	1.1	4.8	
Minimum		3.0	0.5	0.2	0.2	0.02	0.02	2.7	0.7	0.5
Maximum		1300.0	5.2	4.7	0.6	0.08	0.6	8.8	3.8	0.5

		Chromium unfiltered (μg/L)	Copper unfiltered (μg/L)	Iron unfiltered (μg/L)	Lead unfiltered (μg/L)	Manganese unfiltered (μg/L)	Zinc unfiltered (μg/L)	Dissolved Solids dried (mg/L)	Total Nitrogen unfiltered (mg/L)
N	Valid	29	29	13	29	13	29	30	18
	Missing	2	2	18	2	18	2	1	13
Mean		12.0	8.1	5451.3	13.0	539.2	42.0	50.3	6.6
Median		1.0	2.0	1800.0	2.0	400.0	14.0	50.0	5.9
Mode		1.0	1.0	1400.0	1.0	160.0	7.0	50.0	3.0
Std. Deviation		42.3	23.9	5597.4	29.1	358.8	93.8	10.2	4.6
Skewness		5.2	5.1	1.3	4.1	1.3	4.3	1.2	2.7
Kurtosis		27.8	26.4	1.3	18.7	0.4	19.9	2.7	9.5
Minimum		1.0	1.0	867	1.0	160	1.0	36	2.3
Maximum		230.0	130.0	18900	150.0	1300	490.0	84	22.8

Table A8. (continued)

		Rain on day of reading (mm)	Total Rain 7-day prior (mm)	Total Rain 14-day prior (mm)	Total Rain 21-day prior (mm)	Total Rain 28-day prior (mm)	Days of Rain 7-day prior	Days of Rain 14-day prior	Days of Rain 21-day prior	Days of Rain 28-day prior
N	Valid	31	31	31	31	31	31	31	31	31
	Missing	0	0	0	0	0	0	0	0	0
Mean		8.6	23.7	50.5	73.5	96.8	1.6	3.5	5.5	7.7
Median		0	22.9	41.9	72.4	90.9	2.0	4.0	6.0	8.0
Mode		0	0	0	38.9	33.5	2.0	4.0	6.0	8.0
Std. Deviation		14.6	26.1	41.7	44.9	46.1	1.4	2.0	2.4	2.8
Skewness		1.7	1.2	0.4	0.2	0.2	0.6	0.1	1.0	0.1
Kurtosis		1.4	1.6	-0.9	-1.1	-1.2	-0.2	-0.2	1.7	-0.2
Minimum		0	0	0	3.8	33.5	0	0	2	3
Maximum		45.7	105.4	139.5	159.3	189.5	5	8	13	1431

		Rain for week 1 (mm)	Rain for week 2 (mm)	Rain for week 3 (mm)	Rain for week 4 (mm)	Days of rain week 1	Days of rain week 2	Days of rain week 3	Days of rain week 4
N	Valid	31	31	31	31	31	31	31	31
	Missing	0	0	0	0	0	0	0	0
Mean		23.8	26.7	23.0	23.3	1.6	1.9	2.0	2.2
Median		22.9	18.3	21.9	13.0	2.0	2.0	2.0	2.0
Mode		0	0	0	0	2.0	0	0	3.0
Std. Deviation		26.1	28.1	22.5	32.4	1.4	1.5	1.6	1.6
Skewness		1.2	1.1	0.9	2.6	0.6	0.4	0.4	0.3
Kurtosis		1.6	0.4	0.1	6.6	-0.2	-0.8	-0.9	-0.5
Minimum		0	0	0	0	0	0	0	0
Maximum		105.4	103.9	80.3	134.1	5	5	5	6

Table A8. (continued)

		Average Total rainfall 7-day (mm/day)	Average Total rainfall 14-day (mm/day)	Average Total rainfall 21-day (mm/day)	Average Total rainfall 28-day (mm/day)	Average rainfall week 1	Average rainfall week 2	Average rainfall week 3	Average rainfall week 4
N	Valid	21	28	31	31	22	24	23	26
	Missing	10	3	0	0	9	7	8	5
Mean		16.3	13.9	13.5	13.2	15.5	15.1	12.9	10.5
Median		13.7	12.8	13.0	13.0	13.5	12.1	11.3	9.5
Mode		8.0	6.6	5.5	4.8	8.0	6.6	11.3	6.7
Std. Deviation		12.1	10.4	8.6	6.3	12.3	12.9	11.1	7.9
Skewness		1.5	1.9	2.1	2.0	1.4	1.5	2.6	1.0
Kurtosis		3.1	6.1	7.0	7.2	2.9	2.1	8.2	1.2
Minimum		1.3	1.0	1.0	4.8	0	1.0	1.0	0.5
Maximum		52.7	52.7	46.7	37.9	52.7	48.3	53.3	33.5

		Amount of rainfall for first rain prior (mm)	Days prior to reading	Duration of first rainfall (days)	Average first rainfall (mm/day)
N	Valid	31	31	31	31
	Missing	0	0	0	0
Mean		24.3	4.2	1.7	15.0
Median		18.5	2.0	2.0	11.2
Mode		7.4	0	1.0	6.6
Std. Deviation		21.2	4.8	0.7	12.2
Skewness		1.9	0.9	0.6	1.4
Kurtosis		5.9	-0.4	-0.7	2.0
Minimum		1.3	0	1	1.3
Maximum		105.4	14	3	52.7

Appendix B – Mean Annual Total Rainfall to Fecal Coliform Scatter plots with linear regression lines for the Yellow and Alcovy River Basins.

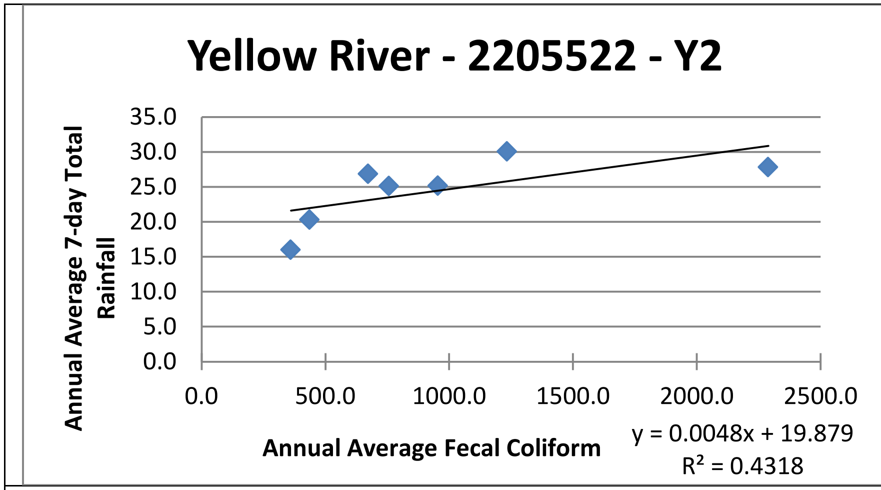

Figure B1. Yellow River Station 2 Annual Average 7 day Total Rainfall to Fecal Coliform Scatter plot with Least-squared linear regression line.

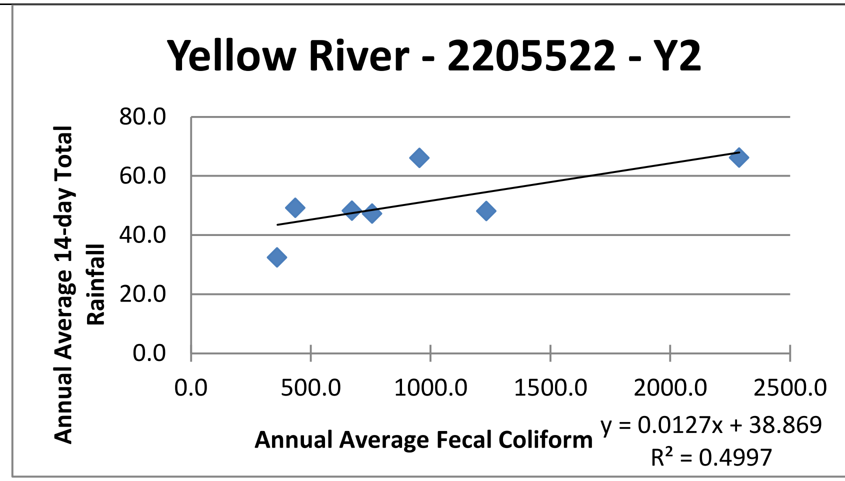

Figure B2. Yellow River Station 2 Annual Average 14 day Total Rainfall to Fecal Coliform Scatter plot with Least-squared linear regression line.

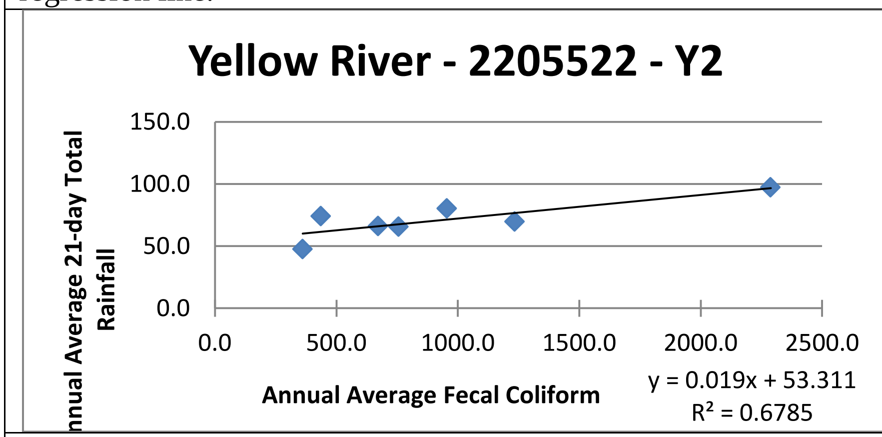

Figure B3. Yellow River Station 2 Annual Average 21 day Total Rainfall to Fecal Coliform Scatter plot with Least-squared linear regression line.

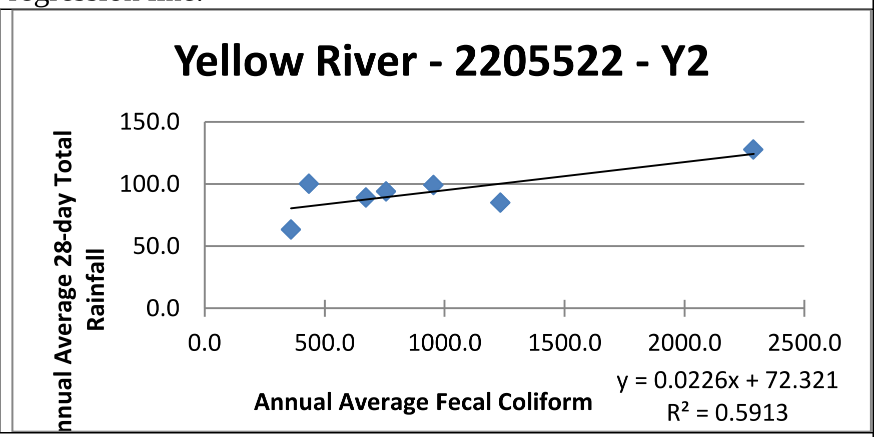

Figure B4. Yellow River Station 2 Annual Average 28 day Total Rainfall to Fecal Coliform Scatter plot with Least-squared linear regression line.

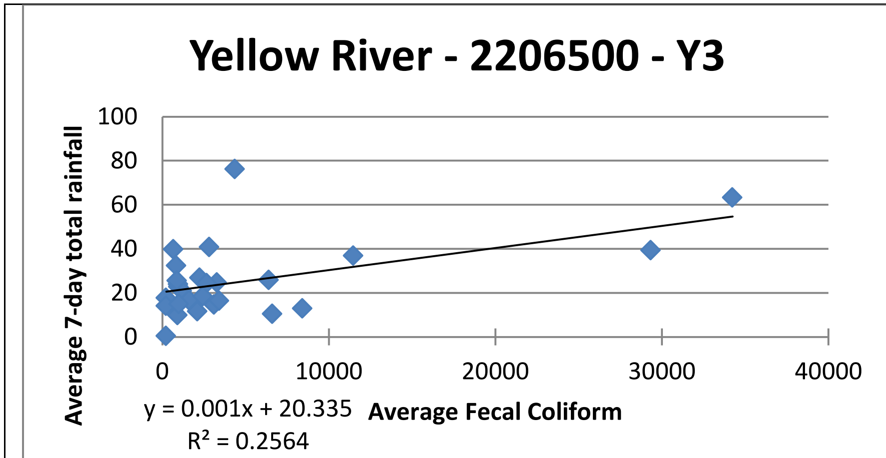

Figure B5. Yellow River Station 3 Annual Average 7 day Total Rainfall to Fecal Coliform Scatter plot with Least-squared linear regression line.

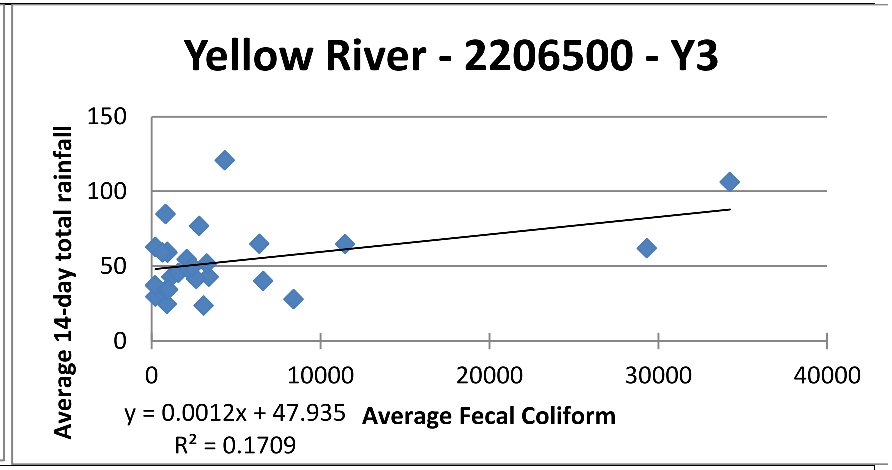

Figure B6. Yellow River Station 3 Annual Average 14 day Total Rainfall to Fecal Coliform Scatter plot with Least-squared linear regression line.

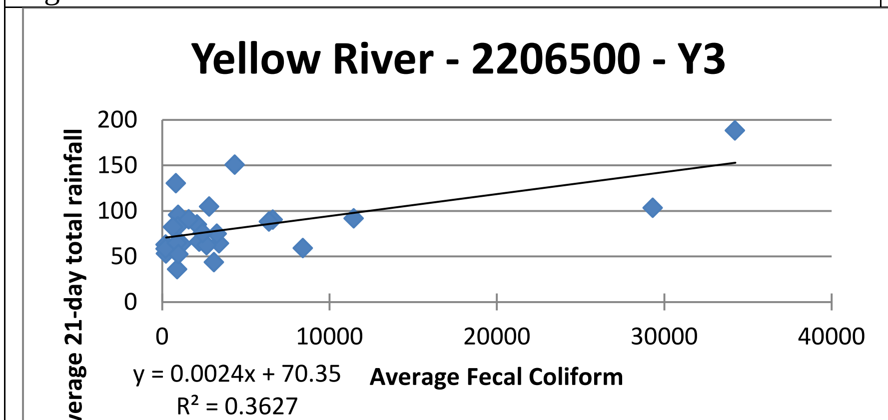

Figure B7. Yellow River Station 3 Annual Average 21 day Total Rainfall to Fecal Coliform Scatter plot with Least-squared linear regression line.

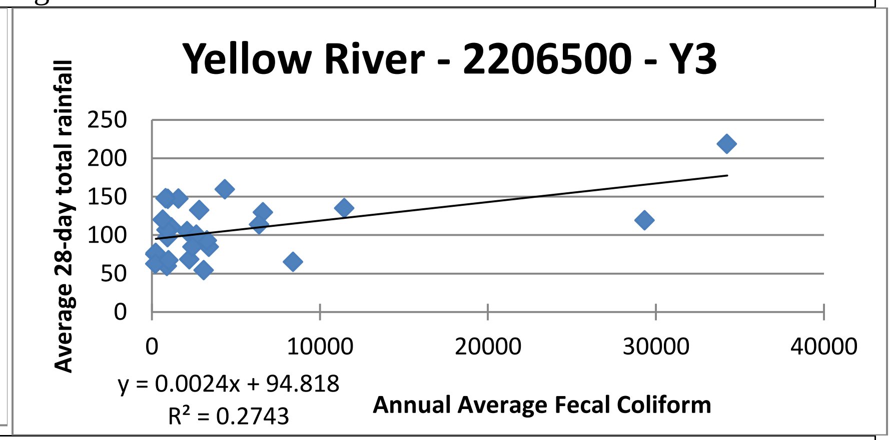

Figure B8. Yellow River Station 3 Annual Average 28 day Total Rainfall to Fecal Coliform Scatter plot with Least-squared linear regression line.

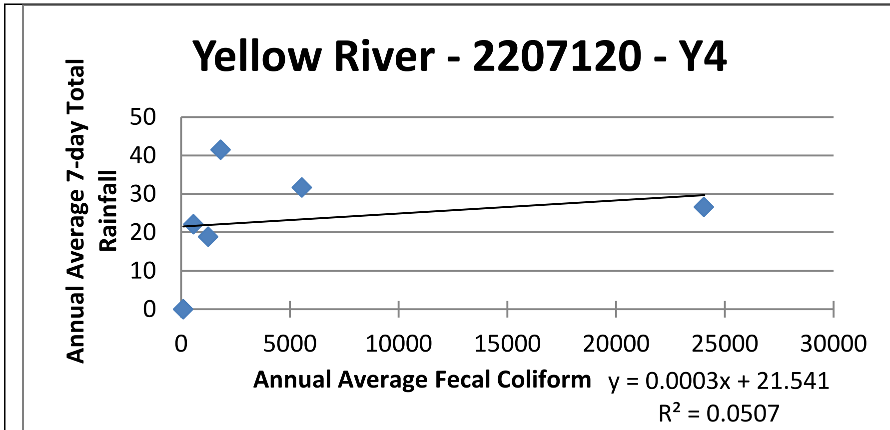

Figure B9. Yellow River Station 4 Annual Average 7 day Total Rainfall to Fecal Coliform Scatter plot with Least-squared linear regression line.

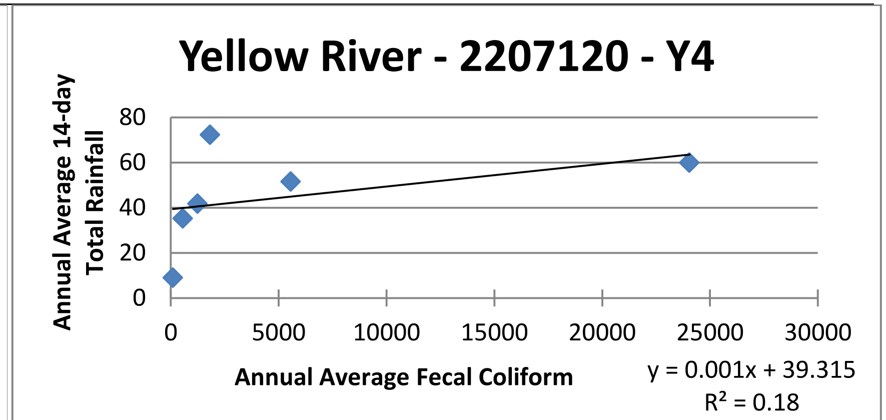

Figure B10. Yellow River Station 4 Annual Average 14 day Total Rainfall to Fecal Coliform Scatter plot with Least-squared linear regression line.

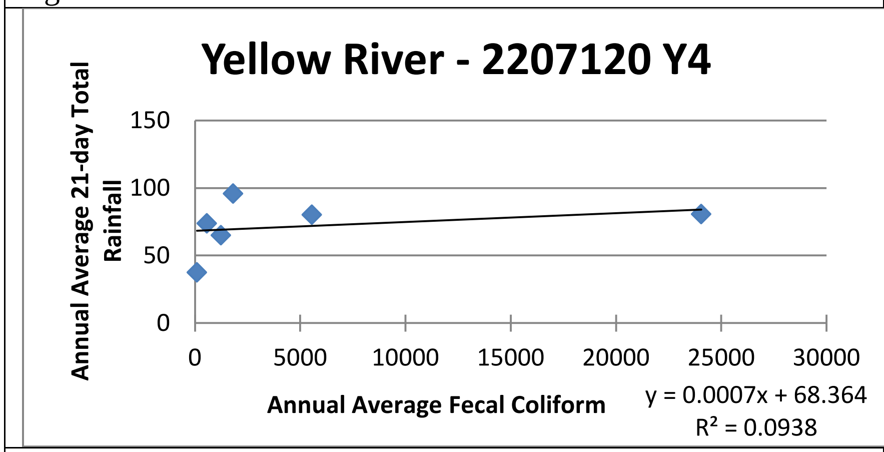

Figure B11. Yellow River Station 4 Annual Average 21 day Total Rainfall to Fecal Coliform Scatter plot with Least-squared linear regression line.

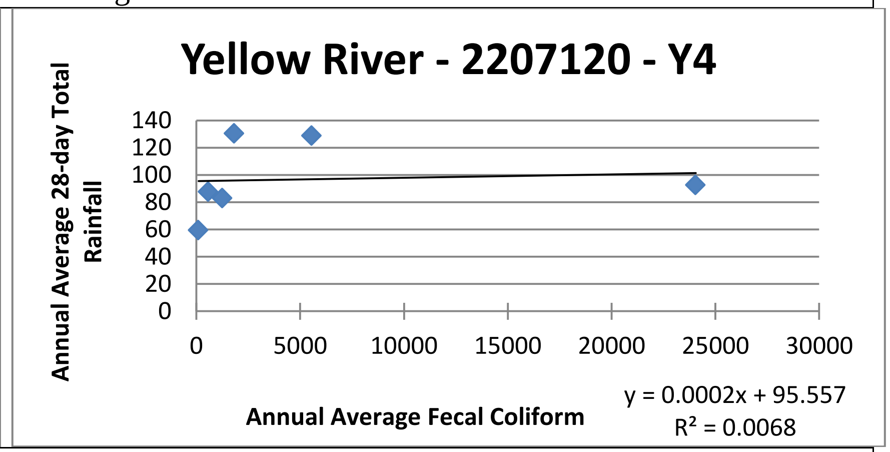

Figure B12. Yellow River Station 4 Annual Average 28 day Total Rainfall to Fecal Coliform Scatter plot with Least-squared linear regression line.

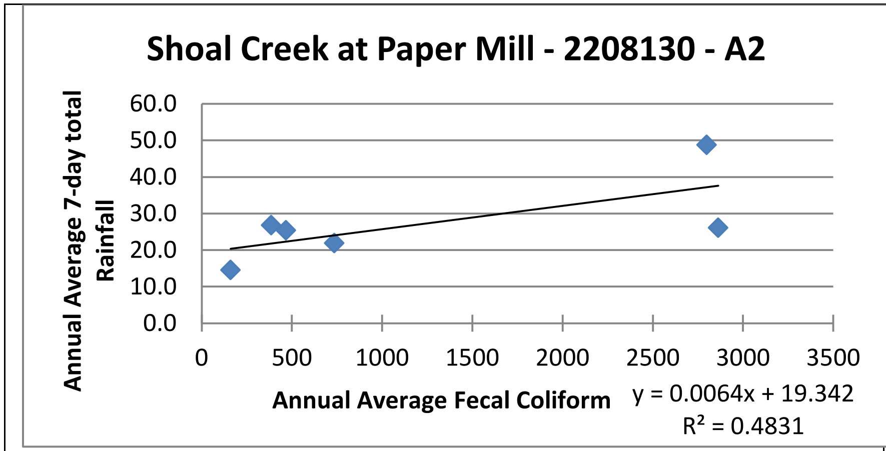

Figure B13. Alcovy River Station 2 Annual Average 7 day Total Rainfall to Fecal Coliform Scatter plot with Least-squared linear regression line.

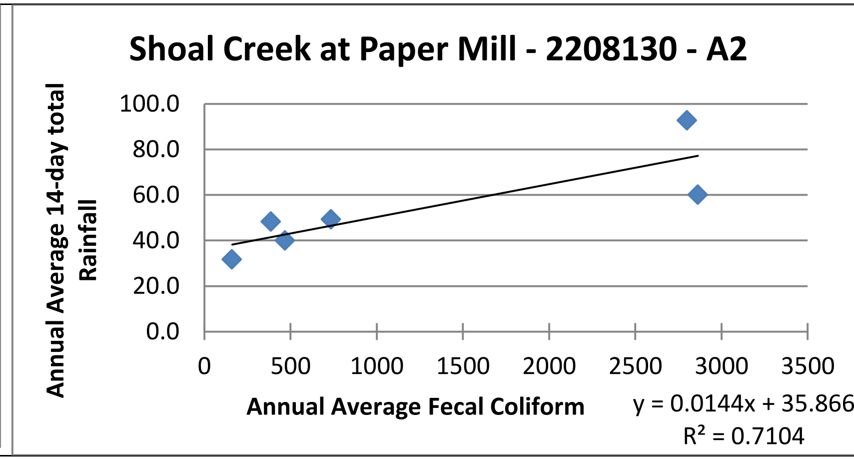

Figure B14. Alcovy River Station 2 Annual Average 14 day Total Rainfall to Fecal Coliform Scatter plot with Least-squared linear regression line.

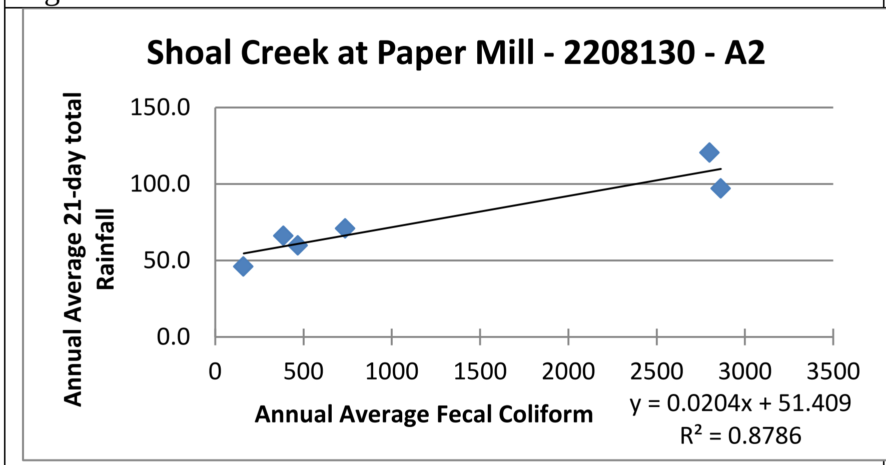

Figure B15. Alcovy River Station 2 Annual Average 21 day Total Rainfall to Fecal Coliform Scatter plot with Least-squared linear regression line.

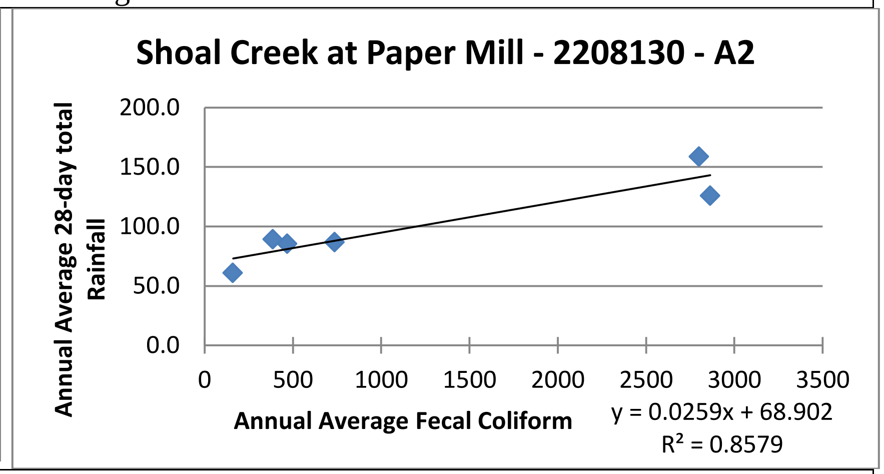

Figure B16. Alcovy River Station 2 Annual Average 28 day Total Rainfall to Fecal Coliform Scatter plot with Least-squared linear regression line.

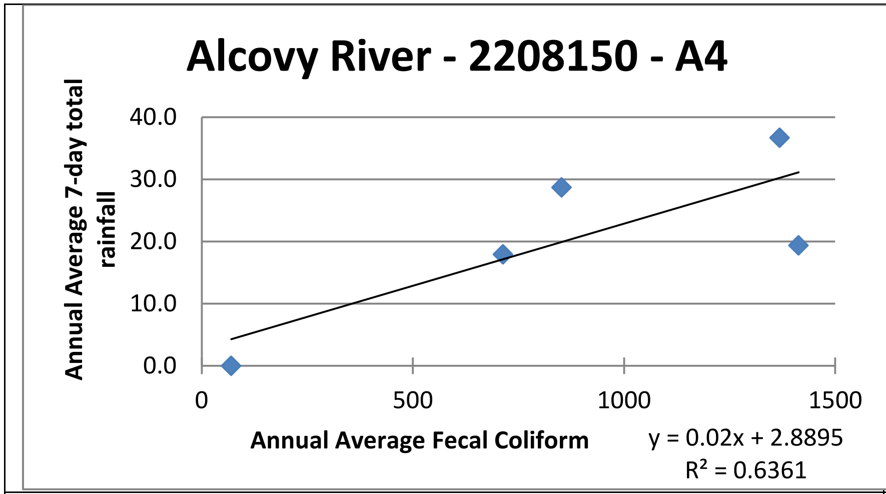	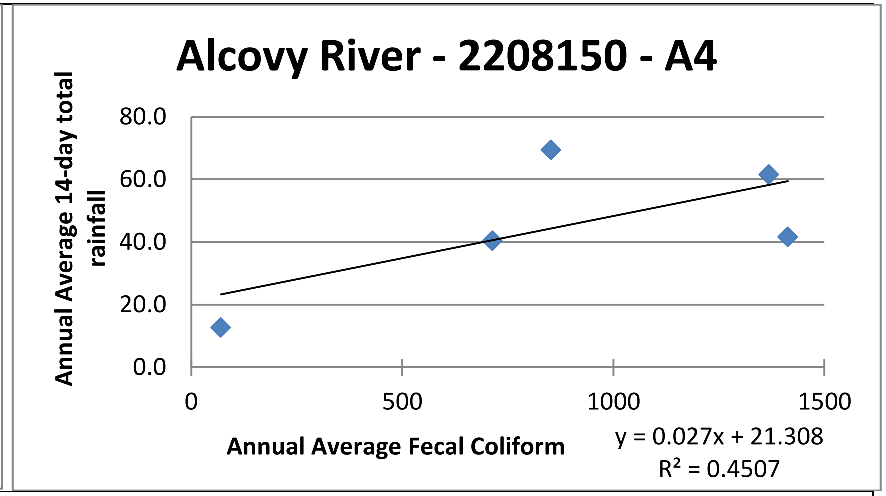
Figure B17. Alcovy River Station 4 Annual Average 7 day Total Rainfall to Fecal Coliform Scatter plot with Least-squared linear regression line.	Figure B18. Alcovy River Station 4 Annual Average 14 day Total Rainfall to Fecal Coliform Scatter plot with Least-squared linear regression line.
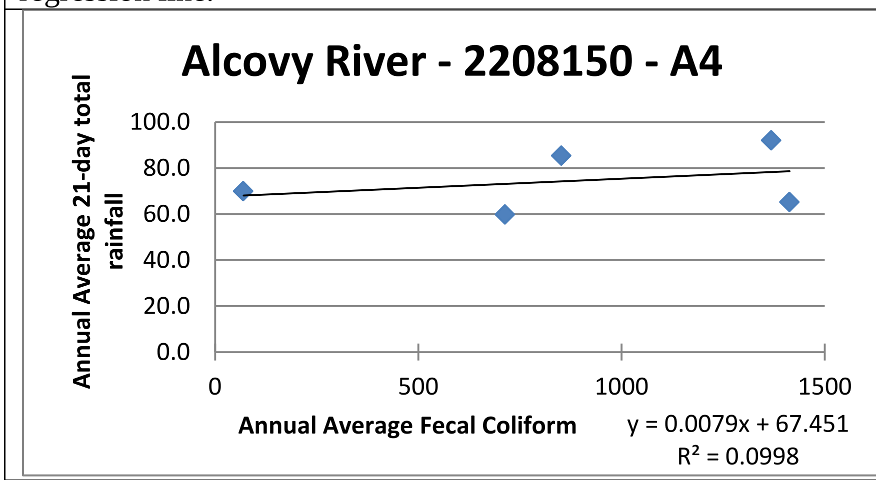	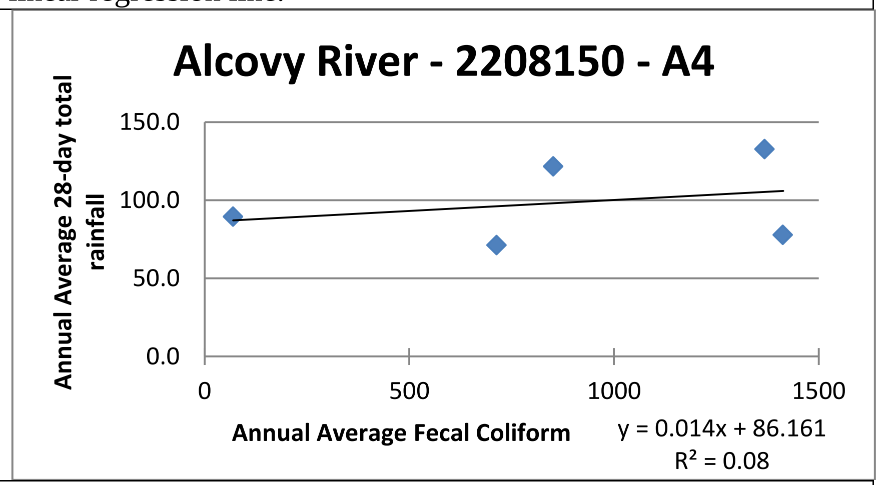
Figure B19. Alcovy River Station 4 Annual Average 21 day Total Rainfall to Fecal Coliform Scatter plot with Least-squared linear regression line.	Figure B20. Alcovy River Station 4 Annual Average 28 day Total Rainfall to Fecal Coliform Scatter plot with Least-squared linear regression line.